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(54) **Signal quality determination in a radio communications apparatus**

(57) Radio apparatus for a radio communications system is disclosed. The radio apparatus comprises

means for determining a period of inactivity for said radio apparatus, and means for determining signal quality of a signal received during said period of inactivity.

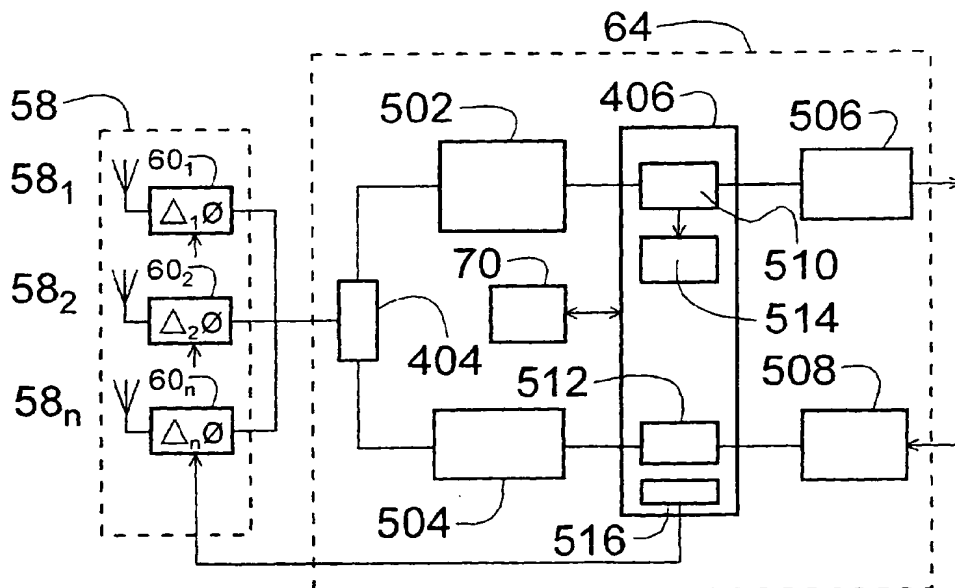


Fig. 5

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Description

[0001] The present invention relates to radio apparatus and radio communications systems, and methods of operation therefor.

[0002] Radio communication systems are well known. For example, cellular radio telephone systems are now an established part of many telecommunications networks, and offer the facility of mobile communications to many users.

[0003] A typical cellular radio telephone system will now be described with reference to Figure. 1. Cellular radio telephone system 100 has three main components: mobile stations (MS) 102 (which term shall be used to include vehicular mounted cellular telephones, portable cellular telephones, and generally radio apparatus used by a subscriber to a radio communications network), base stations (BS) 104, and mobile switching centres (MSC) 106. A mobile station 102 communicates with a base station 104 within a radio cell 108. The base station 104 communicates with the mobile switching centre 106, which routes calls to and from the Public Switched Telephone Network (PSTN) 110, base station 104, other base stations 112 and other mobile switching centres 114. In this manner, a mobile station 102 can communicate with mobile stations in the system, or PSTN subscribers.

[0004] In general, a radio communications system, such as a cellular telephone system, has a region of the radio frequency spectrum allocated to it by a national or occasionally an international authority. Since the allocated radio frequency spectrum is limited to a particular frequency range or ranges, cellular radio systems operators maximise the use of the radio spectrum by restricting the coverage area of a base station 104. The coverage area of a base station 104 is generally termed a cell 108. Cells 108 are usually arranged in clusters 200, and the allocated radio spectrum is divided between individual cells in the cluster. Patterns of clusters 200 are repeated throughout the coverage area of the cellular radio system 100. A 7 cell cluster 200 is schematically illustrated in Figure. 2. However, it should be noted that although the cells 108 are shown having a regular hexagonal shape in practice they are irregular due to the non-homogenous propagation of radio waves through typical terrestrial environments, and usually overlap each other.

[0005] In order to increase the user capacity of a cellular system it is important to be able to re-use frequencies throughout the cellular system. However, re-use of frequencies is restricted by the need to avoid interference between different cells using the same frequencies, so-called co-channel interference.

[0006] Various methods have been employed to reduce co-channel interference and increase system capacity. For example, the base station 104 may transmit adaptive power control signals which dynamically control the mobile station 102 transmit power so that it is

kept just above the minimum level necessary to ensure acceptable transmission quality between the mobile station 102 and the base station 104. Additionally, the overall cell size may be reduced, and the level of power transmitted by respective base stations 104 and mobile stations 102 can be correspondingly reduced, in order to allow for greater re-use of the available radio frequency spectrum. However, a reduction in transmit power can lead to reduced quality of reception and consequently reduced data bandwidth since it is likely to be necessary to repeat transmitted data which failed to transmit correctly a first time more often than with a higher transmit power. Additionally, if cells are smaller then it would be necessary to hand-off a mobile radio apparatus, such as a vehicular mounted cellular telephone, frequently. Such frequent hand-offs between cells may put an unacceptable processing overhead on the cellular radio system.

[0007] A proposed solution to the above-described drawbacks has been proposed in United States Patent No. 5,303,240 issued 12 April 1994. In this patent it is disclosed that a mobile station, and/or base station may be fitted with a steerable beam antenna. The radio network operates in a Time Division Multiple Access (TDMA) mode, and transmits a "training" signal in a training slot for the mobile station 102. The mobile station scans by sweeping the steerable beam and measuring the received signal quality in each beam direction. Once the best direction (i.e. the direction yielding greatest signal quality) has been assigned, normal communications proceed. Since the beam direction is optimal, a minimal amount of power is required for communication, and thus frequency re-use can be increased. At a later time, if it is determined that the chosen beam direction is not correct or optimal, another direction may be selected. However, the overall system capacity may be reduced since useful time slots, or portions of time slots are being utilised to transmit or receive the training signal. Additionally, a mobile station 102 is likely to change its orientation with respect to the base station 104 frequently, and thus the optimum direction will have changed and the received signal power will have dropped below an acceptable level. In the known proposal, the mobile station 102 sweeps the beam direction in order to re-establish the optimum beam direction. However, such sweeping of the beam direction utilises a significant amount of power and time, and it may become an unacceptable processing overhead should the mobile station 102 change orientation frequently or is at the edge of a cell 108. For a system where the base station 104 comprises a steerable beam antenna, a further problem arises when the mobile station 102 is at the edge of the cell. Should the position of the mobile station 102 change, the base station 104 may lose communication with the mobile station and a new call set up would have to be initiated. However, the base station 104 has to first scan or switch into a omni-directional beam mode to re-establish communication with the mobile station 102. In

particular, the omni-directional gain must be sufficient to establish the communications channel with the mobile station 102 despite it being located at the cell edge.

[0008] If the omni-directional gain is not sufficient, then the connection may be dropped. Alternatively, increasing the transmit power would reduce the chance of a call being dropped, but would lead to increased power consumption and hence decreased talk/standby time for the mobile station 102.

[0009] A further drawback is that existing or conventional base stations would require re-programming and/or new transceiver design in order for them to be able to send/receive training signals and/or require the addition of steerable beam antennas.

[0010] The system and apparatus disclosed in United States Patent No. 5,304,240 does not address the problem of a mobile station changing orientation or direction.

[0011] The present invention is directed to improving the performance of radio apparatus and radio communications networks such as, for example but not exclusively, cellular radio networks and mobile stations therefor.

[0012] Particular and preferred aspects of the invention are set out in the accompanying independent and dependent claims. Combinations of features from the dependent claims may be combined with features of the independent claims as appropriate and not merely as explicitly set out in the appended claims.

[0013] In accordance with a first aspect of the present invention, there is provided radio apparatus for a radio communications system, the radio apparatus comprising: means for determining a period of inactivity for said radio apparatus; and means for determining signal quality of a signal received during said period of inactivity.

[0014] In accordance with a second aspect of the present invention, there is provided a method for operating radio apparatus, comprising: determining a period of inactivity for said radio apparatus; and determining signal quality of a signal received during said period of inactivity.

[0015] An advantage of preferred embodiments in accordance with the first and second aspect of the invention is that determination of signal quality does not take up useful transmission or reception bandwidths since it occurs during a period of inactivity. Thus it is not deleterious to the communications bandwidth or data throughput.

[0016] Preferably, the radio apparatus comprises a directional beam antenna, and steering means for determining and steering the antenna beam to an optimum beam direction in accordance with the signal quality of the signal received during the period of inactivity. This is further advantageous in that steering of the antenna beam occurs during a period of inactivity, and therefore does not reduce the available communications bandwidth or data throughput for the device or apparatus.

[0017] In a preferred embodiment, the signal received during the period of inactivity comprises a broadcast sig-

nal. Typically, for apparatus operable in a cellular radio communication system, the broadcast signal comprises a signal from a base station with which the radio apparatus is in primary communication. Such a broadcast signal may be a broadcast control channel signal, e.g. the BCCH signal in the GSM radio telephone system. Embodiments of the invention operable with the GSM system are particularly advantageous since the BCCH signal is continually transmitted at a set power level. Thus, it is a particularly suitable signal for determining signal quality in a particular antenna beam direction, and determining the optimum direction. Evidently, the signal need not necessarily be a continuously transmitted signal, nor indeed have a set transmission power level providing the radio apparatus is capable of determining the periods during which the broadcast signal is transmitted and the level at which it is transmitted.

[0018] Suitably, the broadcast signal comprises any one of a broadcast signal from one or more base stations for cells adjacent the cell for the base station with which the radio apparatus is in primary communication. Thus, it is possible to determine optimum signal direction for communication with adjacent cells. This information can be stored and utilised at a later time when hand-over to one of the adjacent cells is to take place.

[0019] The period of inactivity will typically be a period for which the transmission and/or reception of redundant data has been identified or designated. Such redundant data may be the non-active segments during transmission of silence identity information in voice or speech communication for example, optionally, the period of inactivity may be subsequent to an End of Data signal during data transmission.

[0020] Suitably, the radio apparatus may be a radio communications apparatus such as a radio telephone or the like, or may be included within a base station.

[0021] In a particularly advantageous embodiment of the invention, a period of voice inactivity is determined, during which period the signal quality is measured and the antenna beam is directed towards the optimum beam direction during the period of voice inactivity. Optionally or additionally, a signal representing an End of Data, such as a End of Data Footer utilised in packet data for example, may be identified, and the antenna beam directed and the signal quality measured in a period subsequent to the End of Data signal. This advantageously utilises an inactive period for the radio apparatus for performing the tracking and monitoring of signal quality.

[0022] A further opportunity for identifying or setting up and tracking an optimum beam direction for a period of inactivity is during breakdown in the transmission or reception of a large computer/datafile (e.g. text, graphics/audio and/or video streaming) from the Internet, for example. If an unacceptable error level due to burst errors or Rayleigh fading occurs during transmission/reception, the data or a portion thereof will have to be re-sent. In such a situation, the information being received

is, in effect, non-useful or redundant and, therefore, recalibration or re-setting/tracking of the antenna beam direction may be performed resulting in a net improvement in the performance of the system.

[0023] A yet further opportunity for setting up and tracking an optimum beam direction is when a relatively good signal strength is received at a receiver providing good BER/speech quality, for example. In such a situation, re-alignment of the antenna beam could take place with any degraded or lost data being handled by the error correction routines in the speech vocode or DSP, for example. Thus, the data would be recoverable whilst the antenna beam direction is optimised.

[0024] Particular embodiments in accordance with the invention will now be described, by way of example only, and with reference to the accompanying drawings in which like reference signs are used to denote like parts, unless otherwise stated, and in which:

Figure 1 is a schematic illustration of the basic elements of a cellular radio telephone system;

Figure 2 is a schematic illustration of a seven cell cluster for a cellular radio telephone system;

Figure 3 is a schematic illustration of a radio telephone handset;

Figure 4 is a block diagram of transceiver and base band circuitry for an embodiment of the invention;

Figure 5 is a block diagram of the circuitry of Figure 4 coupled to an antenna array operable in accordance with an embodiment of the invention;

Figure 6 is a diagrammatic illustration of the operation of a directional (adaptive array) antenna;

Figure 7 is a schematic illustration of a mobile station using a steerable antenna in a radio cell;

Figure 8 is a schematic illustration of a TDMA slot arrangement;

Figure 9 is a schematic illustration of an adaptive antenna array operable in accordance with an embodiment of the invention;

Figure 10 is a schematic illustration of an adaptive antenna array system of an embodiment of the invention;

Figure 11 illustrates a flowchart of the steps for setting up and controlling a directional beam antenna for an embodiment of the invention operable for a GSM, or the like, communication system;

Figure 12A diagrammatically illustrates an omnidirectional antenna beam pattern for an antenna operable in accordance with the flowchart of Figure 11; Figure 12B diagrammatically illustrates a 0° to 180° antenna beam pattern for an antenna operable in accordance with the flowchart of Figure 11;

Figure 12C diagrammatically illustrates a 180° to 360° antenna beam pattern for an antenna operable in accordance with the flowchart of Figure 11;

Figure 12D diagrammatically illustrates a 180° to 270° antenna beam pattern for an antenna operable in accordance with the flowchart of Figure 11;

Figure 12E diagrammatically illustrates a 270° to 360° antenna beam pattern for an antenna operable in accordance with the flowchart of Figure 11;

Figure 13A schematically illustrates an antenna beam direction for a change of orientation of a mobile station relative to the base station;

Figure 13B schematically illustrates directing the antenna beam -30° from the previously assigned optimum direction;

Figure 13C schematically illustrates directing the antenna beam +30° from the previously assigned optimum direction;

Figure 14A schematically illustrates a digital data signal;

Figure 14B schematically illustrates an example of a CDMA spreading code;

Figure 14C schematically illustrates the results of the data signal of Figure 14A modulated by the spreading code of Figure 14B;

Figure 15 is a schematic illustration of a CDMA communication system;

Figure 16 is a schematic illustration of a beam pattern for receiving multipath signals having path lengths approximately equal;

Figure 17 is a schematic illustration of an antenna beam pattern for receiving multipath signals having similar path lengths;

Figure 18 is a schematic illustration of an antenna beam pattern for receiving multipath signals having significantly different path lengths;

Figure 19 is a further illustration of a beam pattern for receiving multipath signals having significantly different path lengths;

Figure 20 is a schematic illustration of a beam pattern for receiving multipath signals having significantly greater path lengths than the primary signal;

Figure 21 illustrates a flowchart of the steps for setting up and controlling a directional antenna for an embodiment of the invention operable for a CDMA or the like, communication system; and

Figure 22 illustrates a flowchart of the steps for setting up and controlling a directional antenna for an embodiment of the invention operable for a CDMA system comprising a directional sensor.

[0025] Although the invention finds particular application to cellular radio systems and mobile stations therefor, it also finds application to other radio communication systems and apparatus, for example Public Mobile Radio (PMR), and the terms radio communication system and radio telephone systems include such other systems.

[0026] The basic architecture of a cellular radio telephone system has been described above with reference to Figure 1 and Figure 2.

[0027] Referring now to Figure 3, there is shown a schematic illustration of a portable telephone handset 50 for a cellular radio system 100. The handset 50 com-

prises a housing 64, housing a user interface 52 including a display 54, for example a liquid crystal display, and a keypad 56 typically comprising the numerals 0 through to 9 and some special function buttons. Additionally, the user interface comprises acoustic ports 66 and 68, respectively disposed for a speaker and microphone of the handset. The housing 64 also supports an antenna 58 for the handset 50, coupled to a transceiver (not shown) enclosed within the housing 64.

[0028] Also enclosed within the housing 64 is a directional sensor 70 for sensing changes in orientation of the handset 50.

[0029] A frequency modulated (FM) transceiver and baseband circuitry suitable for use with the radio telephone handset 50 of Figure 3 and typically enclosed within housing 64, will now be described with reference to Figure 4. The transceiver/baseband circuitry 400 of Figure 4 comprises an antenna 58 coupled to an antenna switch 404. The antenna switch 404 may comprise an electronic switching means for switching between the transmit and receive chain of the transceiver, or a diplexer or duplexer operable to filter different receive and transmit frequencies to the appropriate receive and transmit chains of the transceiver. The transceiver/baseband circuitry 400 is controlled by processing circuitry 406 which may comprise a microprocessor, a digital signal processor or other control circuitry e.g. discrete logic circuitry. Additionally, components of processing circuitry 406 may comprise discrete integrated circuits, or may be combined into a single integrated circuit or as part of a multichip module (MCM).

[0030] The transmit chain may be considered to start with microphone 408, the output of which is coupled to audio pre-amplifier 410. The output of the pre-amplifier 410 is coupled to an audio amplifier 412 and a voice activity detector 414. The output from audio amplifier 412 is coupled to the modulation and coding circuitry of processor 406. The output of voice activity detector 414 is coupled to control circuitry of processing circuitry 406, which determines whether or not a voice signal is present at the input to microphone 408.

[0031] Processing circuitry 406 outputs a frequency control signal to frequency synthesiser 416, for determining in which channel a signal is transmitted or received. Additionally, suitably modulated and encoded signals representing speech are output from processing circuitry 406 for further modulation and up-conversion for transmission via antenna 58. The channel frequency is typically determined by a control signal received from the base station 104. The allocated radio frequency spectrum is typically divided into radio frequency channels having a bandwidth of about 25 KHz (which is suitable for most speech applications). Often, the up-link channels (from mobile station to base station) are placed in a frequency band separate from the frequency band for the down-link channels (from base station to mobile station). The output of frequency synthesiser 416 is coupled to a voltage controlled oscillator 418. The output of

synthesiser 416 may be coupled to the voltage controlled oscillator 418 via a frequency multiplier. Optionally, the output of voltage controlled oscillator 418 may be multiplied by an up-converter. In the transmit chain, the output of voltage controlled oscillator 418 (or a multiple thereof) is coupled to RF power amplifier 420. Additionally, the RF power amplifier 420 receives a control signal from control circuitry 422. Control circuitry 422 acts to control the output of the RF power amplifier 420 in accordance with a desired output power such as may be necessary in a cellular system using adaptive power control. Further, control circuitry 422 may form part of a power control levelling loop, which acts to maintain the output power of the RF power amplifier delivered to the antenna 58 substantially constant. This is achieved by monitoring the output of the RF power amplifier 420 and comparing it with a desired signal output level, and adjusting the bias of the power amplifier under the control of circuitry 422, to maintain the desired level. The RF signal is then switched through antenna switch 404 and transmitted via antenna 58.

[0032] The receive chain will now be described in which an RF signal is received by antenna 58 and coupled by antenna switch 404 to a low noise amplifier/filter unit 424. The output of the amplifier/filter unit 424 is coupled to a first mixer 426. Mixer 426 also receives a signal from voltage controlled oscillator 418, under control of frequency synthesiser 416, and outputs an intermediate frequency to an IF filter 428. The intermediate frequency filter 428 provides additional frequency selectivity in order to suppress interference from unwanted adjacent channels, and to reduce the effects of any phase noise introduced by the local oscillator signal from the voltage controlled oscillator 418. The intermediate frequency filter 428 is coupled to a second mixer 430, having a second local oscillator 240 input thereto, which downconverts the intermediate frequency signal to baseband, or suitable frequency for processing circuitry 406, under control of the second oscillator signal from the synthesiser 416. The signal from the second mixer 430 is input to the processing circuitry 406 for any further demodulation and decoding.

[0033] The audio filter 432, typically comprised in an integrated circuit, receives the demodulated and decoded audio signal from the processor 406. The audio filter 432 is coupled to an audio power amplifier 434 which drives a speaker 436.

[0034] A preferred embodiment in accordance with a first aspect of the invention will now be described with reference to Figure 5. Radio apparatus housing 64 includes an antenna switch 404 coupled to the radio frequency front end of the receive and transmit chains 502, 504 respectively. The radio frequency front end 502 comprises the low noise amplifier and filter 424, the first mixer 446, intermediate frequency filter 428 and second mixer 430 together with appropriate inputs from the voltage controlled oscillator 418 and frequency synthesiser 416 described in greater detail with reference to Figure

4. Similarly, the radio frequency front end for the transmit chain 504, comprises a radio frequency power amplifier 420, control circuitry 422 for applying power levelling control and modulating the radio frequency carrier input to the radio frequency power amplifier 420, together with appropriate inputs from the voltage controlled oscillator 418 and frequency synthesiser 416 described in greater detail with reference to Figure 4. Processing circuitry 406 comprises a demodulator/decoder unit 510, for demodulating and decoding received signals. The function of the demodulator/decoder 510 is to output signals to the audio output chain 506 comprising the audio filter 432, audio power amplifier 434 and speaker 436. The demodulator/decoder 510 will operate in accordance with demodulation and decoding schemes suitable for the particular radio communications system in which the radio telephone is operating. Since the particular modulation or decoding scheme is not relevant to the instant invention no further reference to such schemes will be made, except to say that the purpose is to output a suitable audio signal. Similarly, the processing circuitry 406 also comprises an encoder/modulator unit 512 which receives an audio/data signal from the audio receive chain 508 and suitably encodes and modulates the signal ready for outputting to the transmit chain radio frequency front end 504. For reasons mentioned above, no further reference will be made to particular encoding/modulation schemes.

[0035] Processing circuitry 406 also comprises a signal quality level measuring unit 514, which receives an output from demodulator/decoder 510 representative of the received signal. The signal quality level measurement unit 514 may determine signal quality in a number of ways. For example, the received signal strength may be monitored giving a Received Signal Strength Indicator (RSSI), or the bit error rate, the signal to noise ratio, or carrier to noise ratio of the received signal, may be measured. The receive signal quality level, for example RSSI, may be stored for comparison with a later received signal and/or compared with a threshold level.

[0036] The processing circuitry 406 also comprises an antenna beam steering unit 516 for steering the beam of antenna 58. In accordance with a preferred embodiment of the invention antenna 58 comprises a plurality of antenna elements $58_1, 58_2, \dots, 58_n$, each antenna element being driven through respective phase delay and gain circuitry $60_1, 60_2, \dots, 60_n$. The phase delay and gain introduced by respective phase delay and gain elements 60_j is controlled by antenna beam steering unit 516. Such antenna arrays are often termed "adaptive antennas". The steerable beam antenna 58 need not comprise an electronically steerable beam antenna having a plurality of antenna elements, but may be mechanically steerable, or a combination of mechanically and electrically steerable. Under control of antenna beam steering unit 516, the radiation output from antenna 58 may be formed into a relatively narrow beam, and that beam steered to a desired direction. For typical radio

communications system networks the beam need only be steered in the azimuthal direction, that is to say substantially horizontal to the earth's surface. However of course, the elevation of the beam may also be steerable should that be required, although the increased complexity required to provide an extra steerable direction may preclude such a feature on commercial grounds. However, it can be envisaged that certain applications, such as satellite communications applications, may require both azimuthal and elevational steerability.

[0037] Referring now to Figure 6, there will now be described the basic principles of beam forming using an array of antenna elements.

[0038] Figure 6 shows a uniformly spaced linear antenna array 602 with an incident plane wave impinging on the array from an angle θ . The incident wave can be described by:

$$E(t, \vec{r}) = E_0 \exp[j(\omega t - \vec{k} \cdot \vec{r})]$$

where

$$\vec{k} = \frac{2\pi}{\lambda} (-\sin \theta \vec{e}_x - \cos \theta \vec{e}_y)$$

points in the direction of propagation and \vec{r} defines the observation point.

[0039] Taking into account the time delay due to plane wave propagation, the signal at the n -th array element 602_n relative to the signal at the 0^{th} array element is given by

$$x(n) = E_0 \exp[j(\omega t - \frac{2\pi nd}{\lambda} \sin \theta)],$$

where d is the inter-element spacing. Thus when $d = \lambda/2$, the phase difference between the outputs of adjacent elements produced by a plane wave arriving from a direction of θ is $\pi \sin \theta$.

[0040] The fundamental function performed by an adaptive array antenna 602 is to focus a beam in a particular direction for either reception or transmission. The operation of antenna array 602 may be viewed as the spatial counterpart of FIR filtering of a discrete signal in the time domain.

[0041] Commonly, the adaptive array 602 forms a linear combination of the signal received at respective antenna elements $602_{1..n}$ in summation unit 604. Associated with each antenna element 602_j is a weight w_j^* , which modifies the phase and/or signal amplitude of the signal received at respective antenna element 602_j . The set of weights is typically referred to as the steering vector. The steering vector acts as the weights of a spatial filter and determines the gain of the array in a particular direction. In situations where the direction of sources of interference are known, interference mitigation is possible by placing nulls in the antenna pattern in the direc-

tions of interference while simultaneously steering the main beam in the direction of the desired signal. A further discussion of beam forming in phased electronically (scanning) arrays may be found in "Antenna Theory-Analysis and Design", C Balanis, Harper & Row, ISBNo. 06-040458-2.

[0042] Referring now to Figure 7, there is shown a base station 104 for a cell 108. Typically, the base station 104 radiates in a consistent beam pattern preferably using sectorized antennas. Mobile terminals 102 are able to monitor the signal quality from base station 104, and from base stations of adjacent cells in order to determine whether or not the mobile station 102 should hand-off communication with its current base station 104, to an adjacent base station. The mobile station 102 comprises a steerable beam antenna operable to steer the antenna beam 702, through a number of directions 702_a... 702_g. Although Figure 7 shows the antenna radiation pattern as being substantially regular in a given direction, it should be noted that Figure 7 is a schematic illustration and in practice the radiation pattern for the antenna will depend upon the nature of the radiating antenna and the surrounding environment.

[0043] For mobile station 102 antenna direction 702_a provides the best signal quality, and mobile station 102 selects direction 702_a after having swept through antenna directions 702_a... 702_g. If mobile station 102 should move in a direction 704, whilst maintaining its orientation relative to base station 104, it can be seen that the antenna beam direction for optimal signal quality has altered. Thus, it is necessary for mobile station in the new position 102 to steer the antenna beam on to a new direction to form antenna beam 706.

[0044] In a preferred embodiment of the invention the radio communications system is a time division multiple access (TDMA) system such as the GSM (Global System for Mobiles) cellular network, as will hereinafter be described with reference to Figure 8.

[0045] The GSM cellular telephone network operates over an up-link band of 890 to 915 MHz, and a down-link band of 935 to 960 MHz, and is commonly referred to as GSM 900. An alternative GSM network operates at around 1800 MHz and is termed GSM 1800. The GSM network uses TDMA, and respective up-link and down-links are separated into separate radio frequency channels. The carrier frequency for each channel is separated by 200 KHz from adjacent channels, and each of the radio frequency channels is divided into time slots of approximately 577 microseconds (15000/26 microseconds) duration. These time slots are grouped together in sets of eight consecutive time slots as one TDMA frame. These frames are then grouped together in one of two different ways to form multi-frames. The TDMA structure will now be described with reference to Figure 8.

[0046] Figure 8(a) schematically illustrates a single TDMA frame having eight time slots with an overall duration of approximately 4.615 milliseconds, each time

slot having a duration of approximately 577 microseconds. Single TDMA frames may be grouped together to form either a 26 TDMA frame multi-frame having an overall duration of 120 milliseconds as shown in Figure 8(b). Alternatively, the single TDMA frame may be combined as illustrated in Figure 8(c) to form a 51 frame multi-frame having a duration of approximately 235.38 milliseconds. Each numbered frame of Figure 8(b) and (c) comprises a single TDMA frame of Figure 8(a). The 26 frame multi-frame illustrated in Figure 8(b) is used for traffic channels and their associated control channels, and has each slot designated as shown in Figure 8(d) where Ti is a time frame number i for traffic data, A is dedicated for the so-called slow associated control channel (SACCH) and I is an idle frame. A 51 TDMA frame multi-frame is used for the control channel and is shown in Figure 8(e), in which; F is a slot dedicated to a frequency correction channel, S indicates a slot for the synchronisation channel, B indicates a broadcast control channel (BCCH), C is for the common control channel and I is an idle frame.

[0047] Traffic channels carry either encoded speech or user data, and are transmitted in both the up-link and down-link direction. The control channels are transmitted in the down-link direction only, and carry signalling and synchronisation data between the base station 104 and the mobile station 102.

[0048] It is a requirement of the GSM system that the BCCH carrier frequency signal is continuously transmitted in all time slots without variation of the RF power levels, European Telecommunications Standard (ETS) 300 578 "European Digital Cellular Telecommunications System" (phase 2): radio subsystem link control (GSM 05.08), page 18. Maintaining transmission of the BCCH carrier is intended to enable mobile stations to be able to measure the received signal level from surrounding cells by tuning and listening to their respective BCCH carriers. Provided that the mobile station is able to tune to a list of BCCH carriers indicated by the network, it will be able to listen to all possible surrounding cells providing that its list is sufficiently complete. This is useful for the purposes of handover and to determine the appropriate cell with which to communicate based upon the received signal level.

[0049] It is known that speech has a non-continuous nature, and that therefore speech channels carry only one direction of the conversation between two people at any one time. Thus, on average the channel will only be carrying speech for less than half the time it is in use. This fact is exploited in GSM by using discontinuous transmission (DTX). In discontinuous transmission only speech frames which contain samples of "active" speech are transmitted. Discontinuous transmission is implemented using a voice activity detector, labelled 414 in Figure 4, to determine when actual speech is present. However, an entirely silent period is disconcerting to a listener since not even background noise associated with the transmitting party is heard. The sudden

switching from voice, including background noise, and silence is disturbing to a receiving party. In order to overcome this problem the silent frames are replaced by frames filled with so called "comfort noise" which is set to match the amplitude and spectrum of the background noise. Processing circuitry 406 is adapted to analyse the background noise associated with a transmitting party, in order to determine the comfort noise information. The comfort noise information is then sent in the silent period in so called silence identification (SID) frames, to the receiving party (via base station 104 or mobile station 102) where the noise is regenerated. The "comfort noise" information is sent periodically in the silent period and does not necessarily take up the whole of the silent period. In accordance with embodiments of the invention, advantage is taken of the existence of silent periods, and the periodic or non-continuous transmission of "comfort noise" information. During silent periods, a mobile station in accordance with an aspect of the invention is able to monitor the BCCH carrier frequency signal in order to determine the received signal quality level, e.g. RSSI.

[0050] Referring now to Figure 9, there is schematically illustrated a block diagram of an adaptive antenna array 602 controllable by a suitably configured processing means providing control circuitry 902 such as the antenna beam steering unit 516 implemented as a Digital Signal Processor, general purpose microprocessor or logic circuitry. The control circuitry received "raw" or unweighted signals $r_1(k)$ - $r_N(k)$ from respective antenna elements. The control circuitry 902 is configured to operate in accordance with an adaptive algorithm for driving the antenna array 602 and controlling the weighting (w_i) circuitry 904. The weighted output from each antenna element is linearly combined in adder 906, to produce an output $y(k)$.

[0051] The BCCH carrier signal referred to in connection with the GSM system has a constant power level output. For these types of signals advantage can be taken of the *a priori* knowledge of this characteristic and the adaptation algorithm designed to achieve a desired steady state response from the array. For a preferred implementation of the invention, a Constant Modulus Algorithm (CMA) is utilised as the performance criteria that governs the process of adaptively updating the weight vectors 904_i of the individual element 602_i of the array 602.

[0052] The constant modulus adjusts the weight vector 904 of the adaptive array 602 so as to minimise the variation of the envelope of the desired signal at the array. After the algorithm converges, a beam is steered in the direction of the signal of interest, and nulls may be placed in the direction of any interference.

[0053] An alternative embodiment in accordance with the invention will now be described with reference to Figure 10, which illustrates an adaptive antenna array system 1000 suitable for including in a mobile station for a radio communications network. The adaptive antenna

array system 1000 comprises three basic sections; a baseband processing section 1002, a signal digitisation and conditioning section 1004 and an RF front end 1006. In this embodiment, the adaptive array 602 comprises three antenna elements 602₀, 602₁ and 602₂. The adaptive antenna array system 1000 is controlled by a digital signal processor 1008 of the type TMS320C541 made by Texas Instruments Incorporated. Digital signal processor 1008 controls the baseband processing for the mobile station, including forwarding recovered audio to a speaker, and receiving audio from a microphone input. In addition to performing the baseband processing for the mobile station, digital signal processor 1008 also implements the constant modulus algorithm described above for obtaining a steady state of response from the antenna array 602, thereby tracking the constant level signal such as the BCCH signal of a GSM radio telephone network. Digital signal processor 1008 may also be configured to perform other processes or algorithms, such as a set-up or an initialisation process for establishing communication with a base station of a radio network in advance of tracking the optimum signal from that base station.

[0054] Although Figure 10 illustrates the receive path for the adaptive antenna array system, it will be evident to a person of ordinary skill in the art that a transmit path may suitably be constructed using similar or suitably modified elements, based on the principles of reciprocity. The adaptive antenna array system 1000 comprises a separate signal path corresponding to each of the antenna elements 602₀... 602₂. Operation of the adaptive antenna array system 1000 will now be described with reference to one of the received signal paths.

[0055] Antenna element 602₀ is coupled to a first band pass filter 1010, which acts to discriminate a received signal, from other unwanted signals falling outside the received band. The band pass filter signal is forwarded to an amplifier 1012, typically a low noise amplifier, and then forwarded on to mixer 1014. A local oscillator 1016 provides a second input to mixer 1014 and acts to down-convert the received signal to a target intermediate frequency which is then input to a second band pass filter 1018. Band pass filter 1018 acts to discriminate the target intermediate frequency signal, from other co-channel signals and other sources of interference. The intermediate frequency signal is then forwarded to an intermediate frequency amplifier 1020 and then to an analogue digital converter 1024 which is clocked in accordance with system clock 1022. Analogue digital converter 1022 provides a 12 bit output to digital to digital converter 1026. The digital to digital converter 1026 provides a 16 bit input suitable for digital signal processor 1008, over the digital signal processor back-plane interface 1009.

[0056] Digital signal processor 1008, operating in accordance with the constant modulus algorithm described above (or other suitable algorithm) controls the beam formed by antenna array 602 to receive the opti-

imum signal. In the adaptive array system 1000 of Figure 10, control of the phase and/or amplitude of signals received for respective antenna elements may be effected by local oscillator 1016. By adjusting the phase and/or amplitude of the local oscillator 1016 signal the digital signal processor 1008 can modify the phase and/or amplitude of the resulting intermediate frequency signal. In accordance with the principle of reciprocity, the same may be achieved in the transmit signal path direction. Thus by appropriately adjusting the local oscillator phase and/or amplitude of respective local oscillators 1016 the weight factors of the adaptive array may be modified.

[0057] Optionally, the adaptive antenna array system illustrated in Figure 10 may be modified to have only one received signal path, and to have each antenna element associated with a separate weight adapter, wherein respective signals received by respective antenna elements are summed prior to being forwarded through the rest of the RF front end. Such a configuration is as illustrated in Figure 9. For the configuration of Figure 9, the digital signal processor 1008 would operate directly on the weight factors 904 to adjust the phase and/or amplitude of respective signals received from respective of antenna elements. Although the particular configuration of the adaptive antenna array system may vary, the principle of operation of steering and controlling an adaptive antenna array system will be evident to a person of ordinary skill in the art.

[0058] Having now described various embodiments of adaptive antenna array systems and configurations for controlling and forming beams from such antenna arrays, an algorithm for setting up and controlling a steerable antenna in accordance with an embodiment of the present invention suitable for a GSM radio network system or the like, will now be described with reference to the flow chart illustrated in Figure 11.

[0059] The flow chart of Figure 11 starts at step 1102, and the gain and phase of gain and phase delay circuitry 60₁... 60_n of the embodiment of Figure 5 (or suitable weight factors 904 of the embodiment illustrated in Figure 10) are set for an omni-directional beam pattern as illustrated in Figure 12(a). With an omni-directional beam pattern, a mobile station 102 is able to make communication with a least one base station 104, and typically more than one base station associated with respective cells within whose influence the mobile station 102 is located. At step 1106 the baseband circuitry comprised in the processing circuitry 406 of the embodiment illustrated in Figure 5, or the digital signal processor 1008 of the embodiment illustrated in Figure 10, decode the BCCH signals received from respective base stations in order to determine their signal quality. Typically the measure of signal quality is a measure of the RSSI of the received signal. The mobile station 102 sets its receive carrier frequency to the selected base station, typically that providing the greatest RSSI, at step 1108. At step 1110 the signal quality may be measured again,

typically the signal strength, and the value "N" stored.

[0060] At step 1112, the mobile station processing circuitry 406 determines whether or not a SID frame is present in the received traffic channel. If no SID frame is present then the process flow may return to step 1102, and the omni-directional beam pattern as illustrated in Figure 12(a) maintained. If a SID frame is present then the yes arm of decision block 1112 is processed and the process flows to step 1114 in which the gain and phase for the gain and phase delay circuitry 60 (weight factors 904) are set for a beam width of zero to 180°, with a bore-sight direction $X = 90^\circ$ relative to a suitable reference plane of the mobile station 102, as illustrated in Figure 12(b). Process control then flows to step 1116 where the RSSI of the received CCH signal from the selected base station is stored as value "Mx". Control of the mobile station 102 then flows to decision block 1118 where it is determined whether or not the stored RSSI value MX is greater than the stored RSSI value N.

[0061] For MX greater than N control flows to step 1126, otherwise control flows to step 1120 where the gain and phase of the gain and phase delay circuitry 60 (weight factors 904) are set for a beam width from 180° to 360°, where the bore sight direction X equals 270° as shown in Figure 12(c). Control then flows to step 1122 where the RSSI value MX of the BCCH signal of the selected base station is stored for the current antenna beam pattern. The stored value MX is then compared with the stored RSSI value N at step 1124. If RSSI value MX is less than N then control flows back to 1104. However, if MX is greater than N then the value of MX is assigned to N, and the new value N is stored at step 1126. Process control then flows to step 1128 where the gain and phase of gain and phase delay circuitry 60, or the weight factors 904, are set to form a beam width from $X - 90^\circ$ to X. A new boresight direction X is then set to equal the previous value for X - 45° as illustrated in Figure 12(d). The process then flows to step 1130 where the RSSI value MX is measured and stored. The process then flows to decision block 1132.

[0062] At decision block 1132 the current value of MX is compared with the current value assigned to N to determine whether or not MX is greater than N. If MX is greater than N then flow control jumps to step 1140. Otherwise flow control proceeds to step 1134 where the gain and phase of the gain and phase delay circuitry 60 or weight factors 904, are set to form a beam width of X to $X + 90^\circ$, where X is assigned a new value equal to the old value $X + 45^\circ$ as shown in Figure 12(d). Control then flows to step 1136 where the RSSI is measured and assigned to MX and stored. Process control then flows to decision block 1138 where it is determined whether or not MX is greater than N. If no, then the process control flows back to the start of the process, step 1104 and if yes flows to step 1140 at which point the current value MX is assigned to N. The process control then flows to decision block 1142.

[0063] Process control steps 1102 through to 1140

have initialised and set up the steerable beam antenna for the optimum beam direction for communication with the base station 104 designated for the mobile station 102.

[0064] The mobile station 102 now can be configured to operate in a second mode in which the optimum beam direction is tracked in order to maintain optimum communication with the base station as the mobile station 102 changes its orientation with respect to the base station 104. In a preferred embodiment tracking is achieved by steering the beam either side of the recorded optimum signal direction, e.g. $\pm 30^\circ$ to measure signal quality in those directions.

[0065] Having established an optimum communication link with a base station, it is necessary to determine whether or not there has been a request to hand off to another base station 104. Such an investigation may be initiated by the fact that the orientation of the mobile station as shown in Figure 13(a) has changed and the antenna beam is no longer pointing directly at the base station 104. If it is determined that the base station has instructed a change in the base station with which the mobile station is communicating, then control of the process returns to the start, step 1102, and the base station either instructs the mobile station to enter the omnidirectional mode, or the mobile station does it automatically when instructed to change base station. Then the optimum antenna direction for the new base station is determined. Otherwise, when there is no change in base station, the process control flows to step 1144 where it is determined whether or not a SID frame is present in the traffic signal received by the mobile station 102. If no SID frame is present in the received traffic signal then the process flow control returns to step 1142 where a change in the base station is monitored. Otherwise, the gain and phase delay values for the gain and phase circuitry 60, or the weight factors 904, are set to provide a beam width from $X - 75^\circ$ to $X + 15^\circ$ as shown in Figure 13(b). Process control then flows to step 1148 where the RSSI value MX_{-30} for the direction $X - 30^\circ$ is determined, and stored. At step 1150 it is determined whether or not MX_{-30} is greater than N. If yes then at step 1152 X is assigned the value $X - 30^\circ$ and N is set to equal MX_{-30} .

[0066] Process control then flows to step 1142 in order to begin the tracking process again. However, if MX_{-30} is not greater than N then process control flows to step 1154, and the gain and phase of the gain and phase delay circuitry 60, weight factor 904, is set to provide a beamwidth extending from $X - 15^\circ$ to $X + 75^\circ$ as shown in Figure 13(c). The process then flows to step 1156 where the RSSI value MX_{+30} for the direction $X + 30^\circ$ is measured and stored. The value MX_{+30} is then compared with N to determine which is the greater. If MX_{+30} is greater than N then process control flows to step 1160 where X is assigned the value $X + 30$ and N is assigned the value MX_{+30} . Otherwise process control flow returns to step 1142.

[0067] An adapter antenna array, or other form of steerable antenna operated in accordance with the foregoing described process is able to identify an optimum beam direction, and track at optimum beam direction as the orientation of the mobile station is changed.

[0068] In the foregoing process the directional beam has been utilised to reject multipath beam reception, that is to say reception of beams which due to the environment and reflections from objects in the environment have taken multiple paths to arrive at the mobile station. In this manner the performance of the mobile station may be significantly improved. Due to the principle of reciprocity, there is a corresponding improvement in the signals received by the base station, or a lower transmit power for the same performance.

[0069] It will be appreciated that the process described above for identifying and tracking the optimum antenna beam direction is a "background" process for the mobile station 102, and may be interrupted at appropriate points in order for other operations of the mobile station 102 to be performed.

[0070] In an alternative embodiment decision blocks 1118, 1124, 1132, 1138, 1150 and 1158 also comprise a test for whether a SID frame is still present or not. If a SID frame is still present then the process flow continues. However, if a SID frame is not present then the process flow is stalled until a SID frame is present again. As mentioned above, the process flow in this alternative embodiment is a "background" process and may also be stalled at appropriate points in order for other operations of the mobile station 102 to be performed.

[0071] The foregoing description is in respect of a GSM radio telephone system. An embodiment of the present invention may also be utilised in a CDMA radio telephone system.

[0072] A brief description of the general principles of CDMA will now follow, with reference to Figures 14 and 15 of the drawings. A data signal as shown in Figure 14 (a) is modulated by a CDMA spreading code illustrated in Figure 14(b). Although only a data signal is illustrated in Figure 14(a), the data signal may previously have been modulated by an RF carrier signal. However, in the case of a digital signal, it is usually the fact that data modulation is omitted and the data signal is directly multiplied by the code signal which modulates the carrier frequency.

[0073] The result of the spreading code multiplied by the data signal is illustrated in Figure 14(c). The code signal consists of a number of code bits called "chips" which can be either +1 or -1. In order to obtain a suitable spreading of the data signal, the chip rate of the code signal must be much higher than the chip rate of the information or data signal. A figure of 10 code chips per data or information signal is a typical ratio, resulting in a processing gain of 10. The spread signal as illustrated in Figure 14(c) is then transmitted.

[0074] Referring now to Figure 15, there is provided a simplified diagram of a CDMA system. A data signal

1502 a id code signal 1504 originating from code generator 1506 are input to mixer 1508. The spread data signal 1510 is then input to modulator 1512 for modulating a radio frequency carrier. The modulated signal 1514 is then transmitted into the environment which is modelled as a multi-path channel 1516.

[0075] In the example illustrated in Figure 15, the radio propagation environment is modelled as three separate channels having different delays τ_1 , τ_2 and τ_3 with corresponding attenuation factors a_1 , a_2 and a_3 . The three separate multi-path signals effectively combine, 1518, at the antenna for the receiver and are forwarded to the demodulator 1520.

[0076] The signal from the demodulator is input to a so-called RAKE receiver 1522, which has a finger for each multi-path component it is desired to decode. The signal 1524 output from the demodulator 1520 is split into each of the fingers, 3 in the present example, and forwarded to respective mixers 1526, 1528 and 1530. Input to respective receivers 1526, 1528 and 1530 are respectively delayed spreading codes $C(T-\tau_1)$, $C(T-\tau_2)$ and $C(T-\tau_3)$, where the spreading code C corresponds to that in code generator 1506. The signal output from respective modulators is input to respective gain circuitry a_1 , a_2 and a_3 , corresponding to the attenuation experienced in the multi-path environment. The attenuated signals 1532, 1534 and 1536 are then combined at 1538 and forwarded to further demodulation and coding circuitry of the receiver.

[0077] CDMA systems utilise the reception of multi-path signals, whereas TDMA systems, such as the GSM system described above, seek to reject multi-path signals. A RAKE receiver, such as described with reference to Figure 15, receives the multi-path signals and correlates them with the receiver spreading code in order to coherently combine them to provide a single received signal at the output of the RAKE receiver. In order to optimise a received signal in a CDMA system, the beam pattern may be configured during a beam set-up procedure to take into account the desire to optimise for multi-path signals. Once the beam pattern has been defined, then realigning the beam pattern in order to track the optimum configuration for changes in orientation of the mobile station 102 is similar to that as described above for the GSM system. That is to say, the output from the RAKE receiver is monitored in order to maintain maximum received signal strength.

[0078] Such a foregoing method is based on the assumption that the mobile station stays substantially in the same position within the multi-path environment whilst changing its orientation. However, if the mobile station 102 should move a sufficient distance within the multi-path environment, such that the direction of the received signals are significantly changed, then it may be necessary to enter a set-up procedure again in order to first find the antenna beam configuration for receiving optimum signal strength, and then subsequently tracking the signal strength as the orientation of the mobile

station 102 is varied.

[0079] For a mobile station 102 disposed in a multi-path environment, there is a correlation between the delays used in the RAKE receiver for correlating each multi-path signal with the receiver spreading code, and a direction of arrival of the corresponding multi-path signal. Thus it is possible, to at least a first order approximation, for the beam pattern to be configured for maximum received signal strength on the basis of the delays for respective multi-path signals. Examples of suitable beam pattern configurations for various time delays between multi-path signals are illustrated in Figures 16 to 20.

[0080] Figure 16 schematically illustrates a MS 102 and BS 104 communicating within a multi-path environment. The multi-path environment is defined by reflectors 1601 and 1602. The MS 102 receives a direct or primary signal T_0 and two indirect or reflected signals T_1 and T_2 . The primary signal path T_0 will be used as a reference path or signal. In the Example of Figure 16, both the primary signal and reflected signals are incident at the MS 102 from directions within the same sector as the primary path signal T_0 . Thus, there is a very small difference in the time delays utilised by the RAKE receiver and correlating the reflected signals T_1 and T_2 with the primary path signal T_0 . Since the signals all arrive within the same sector as each other, it is possible to configure a single narrow lobe beam pattern for maximising received signal strength. Thus, there is found a correlation between small time delays utilised in the RAKE receiver and a narrow beam-width pattern such as illustrated in Figure 16.

[0081] For the multi-path environment illustrated in Figure 17, the reflectors 1603 and 1604 forming multi-paths T_1 and T_2 respectively, are disposed further away from BS 104 compared to the environment illustrated in Figure 16. Thus, multi-paths T_1 and T_2 are no longer approximately equal as is the case in Figure 16, but merely similar to path T_0 . In this instance, the delays applied in the RAKE receiver are greater than those used in the situation illustrated in Figure 16. Additionally, the multi-path signals arrive from a broader angle of direction than before and consequently the beam pattern configuration requires expansion in order to maximise the received signal. Suitably, the beam pattern is a 180° beam pattern having a bore sight substantially on the primary path T_0 . For a situation such as illustrated in Figure 17, a set of delays applied in the RAKE receiver may be set to correspond to a need for a broad 180° beam pattern.

[0082] Turning now to Figure 18, there is illustrated a situation where one of the paths, T_1 is much greater than the primary signal path T_0 . Multi-signal path T_2 is approximately equal to primary path T_0 . In the situation illustrated in Figure 18, the direction of the primary path signal T_0 is first identified. The identification of the sector in which the T_0 primary path signal occurs may be attained by a suitable setup routine, such as described for

the GSM system with reference to the flowchart of Figure 11. For such a setup routine, a relatively narrow beam-width pattern is established in the direction of the greatest received signal strength which becomes the primary path direction. Once the beam pattern for the primary path signal is established, which in the example illustrated in Figure 18 also includes multi-path T_2 , then the direction of the signal corresponding to a large delay needs to be identified. However, a signal having a delay such as that illustrated in Figure 18 may also comprise a signal path designated T_2 in Figure 19. Thus, the delay of the secondary signal in Figures 18 and 19 does not provide information regarding the direction of arrival but only the magnitude of the angle of offset relative to the direct path signal T_0 . Thus, for signals having a large delay, the antenna beam patterns as illustrated in Figures 18 and 19 should be respectively utilised, and the one with the higher signal strength selected for operation. Thus, signals having large delays correspond to two different antenna beam patterns as illustrated in Figures 18 and 19.

[0083] Figure 20 illustrates a situation where both delayed signal paths T_1 and T_2 arrive at MS 102 from directions which involve considerable delay relative to the direct signal path direction T_0 . As illustrated in Figure 20, the delays for the signal paths T_1 and T_2 are effectively a combination of the scenarios illustrated in Figures 18 and 19. However, it is possible that the signal path delays are increased even further and that the delayed signals arrive at the MS 102 from the opposite direction to BS 104, and thus an antenna beam pattern configuration utilising rear lobes is necessary to fully optimise received signal strength.

[0084] As will be evident from the foregoing discussion with reference to Figures 16 to 20, it is possible to derive a set of antenna beam configurations for optimising received signal strength, corresponding to the delay (s) utilised by the RAKE receiver when correlating the multi-path signals. Once a suitable beam pattern has been defined, then providing the MS 102 remains substantially in the same place within the multi-path environment, changes in orientation for the MS 102 may be tracked as described with reference to the flowchart of Figure 11. Should the MS 102 change position within the multi-path environment, make a rapid change in orientation or the RAKE receiver delays vary beyond determined limits, it will be necessary to set up the antenna beam configuration for optimum received signal strength again.

[0085] The absolute difference between the time of arrival of a primary signal and a multi-path signal, for a given received angle of incidence, is dependent upon the distance between the mobile station 102 and the base station 104. The greater the difference between the mobile station and the base station then the greater the delay between the time of arrival of the primary path signal and the multi-path signal. Thus, relying on the delay alone in order to determine the angle of incidence of

a received multi-path signal relative to the primary path signal may result in an error in evaluating the angle of incidence. However, in a CDMA system, the BS 104 operates on receiving signals of substantially the same power level for all MS 102 with which it is communicating. In order to achieve this, the BS 104 transmits power control signals to the MS 102 with which it is communicating, indicating which power level they should be transmitting on, in order for the BS 104 to receive signals having substantially equal power levels. Thus, the MS 102 has information corresponding to the distance from the BS 104 by virtue of the power control level signal received from the BS 104. This distance information may be utilised to normalise the angle of incidence, calculated with respect to the delay, to produce a so-called "spreading factor" A. The spreading factor A normalises the delay information and the distance information derived from the transmitted power level for the MS 102. The spreading factor A can then be utilised as a factor by which the evaluated delay may be multiplied, in order to determine which of a set of predetermined antenna beam patterns should be used to optimise received signal power level. In the present example, the larger the spreading factor A, the smaller the angle of arrival of incidence of the multi-path signal relative to the primary path signal. Thus, for a large spreading factor, a relatively narrow beam pattern (for example 90° beam width) may be utilised. If, however, the spreading factor is small, that is to say the transmit power level from the MS 102 is small indicating that the separation of the MS 102 and BS 102 is small, and the delays applied to the RAKE receiver are large, it will be indicated that the multi-path signals are incident on the MS 102 at large angles of incidence in which instances, one would establish a relatively large beam width antenna pattern, (e.g. 180°). The principle will also apply to situations where there are very large values for the spreading factor A and very large values for the delay applied to the RAKE receiver. In such an incidence, the multi-path signals are incident from behind the MS 102 relative to the direction of the BS 104 and it would be necessary to generate a beam pattern which was either omni-directional or directed to a 270° pattern or to a complex beam pattern such as that shown in Figures 18 to 20.

[0086] The process for setting up and controlling a steerable antenna for a CDMA system incorporating the use of a spreading factor a, will now be described with reference to the flow chart illustrated in Figure 21.

[0087] The process control starts at step 2102 and proceeds to step 2104 where the antenna boresight direction, X, is set to zero. At step 2106, the gain and/or phase of delay elements 60 are set for an omni-directional beam pattern as illustrated in Figure C1. At step 2108, the received synchronisation signals are coded and the primary path T_0 is established. Next, step 2110, the spreading sequence for the MS 102 is set to that defined by the base station for the particular communication channel in use. At step 2112, the received signal

strength from the output of the RAKE receiver is measured and stored as N. Additionally, the spreading factor A is set. Next, the process control flows to step 2114 at which it is determined whether or not a SID frame or an end-of-packet footer is present in the received information signal. If no such frame or footer is present, then the process flow returns to step 2106. However, if a SID frame or end-of-packet footer is present, then process control flows to step 2116 where the gain and phase differences for the antenna is set to produce an antenna beam pattern having 180° beamwidth and boresight direction of 0° as shown in Figure C2. Next, step 2118, the received signal strength is measured from the output of the RAKE receiver and stored as value MX, where X is the antenna boresight direction.

[0088] At step 2120, it is determined whether or not MX is greater than N. If not, then the process control flows to step 2122 where the antenna boresight direction X is set such that $X = X + 180^\circ$ to produce the antenna beam pattern as shown in Figure C3. At step 2124, the received signal strength from the output of the RAKE receiver is measured and stored as value MX. Again, at step 2126, the value MX is compared with value N to determine whether or not MX is greater than N. If not, then the process control flows back to step 2106 where determination of a preferred or predominant direction for received signals is restarted. Next, step 2128, the process flow proceeds from step 2126 or a "yes" decision and also from step 2120 for a "yes" result. At step 2128, the value N is set to equal the value MX. At step 2130, it is determined whether or not the delay of one or other of the multi-path signals T_1 , T_2 with respect to the primary signal T_0 , in absolute terms, is less than the chip duration multiplied by the spreading factor A. The product chip duration multiplied by A is a threshold value for the delays in multi-path signals with respect to primary path signals, and may be derived by relationships other than that illustrated. A "yes" result at step 2130 would indicate that either the delays were small, and thus the multi-path signals were arriving from substantially the same direction as the primary path signal corresponding to the antenna beam button illustrated in Figure C2 or Figure C3 where the primary signal path direction is given by X which in the particular Examples is 0° or 180°. For a "yes" result, the process control flows to step 2146 where it is determined whether or not the beam can be narrowed to focus onto a particular direction for received signals. If the result at step 2130 is "no", then the process control flows to step 2132 where the antenna boresight direction is shifted to 90° as shown in Figure C4, by setting $X = X - 90^\circ$. At step 2134, the signal strength output from the RAKE receiver is measured and stored as value MX. The process control then flows to step 2136 where it is determined whether or not MX is greater than N, the previously stored value of the received signal strength output from the RAKE receiver.

[0089] If the result of step 2136 is "yes" then process control flows to step 2144 where N is set to the value

MX. If the result from 2136 is "no", then process control flows to step 2138 where the antenna boresight direction is changed to be 270° as shown in Figure C5, by setting $X = X + 180^\circ$. At step 2140, the signal strength output from the RAKE receiver is measured and stored as value MX. At step 2142, it is determined whether or not MX is greater than N. If the result of the step 2142 is "no", process control returns to step 2106, and if the answer is "yes" the process control flows to step 2124 where N is set to equal MX. Thus, it is determined whether the optimum received signal lies in the half-plane having its boresight direction at 90°, or at 270°.

[0090] At step 2146, the process flow proceeds for the optimum signal direction having been established as occurring in the half-plane determined by 0° or 180° as shown in Figures C2 and C3, respectively. At step 2146, the value N is set to be value MX, as determined for respective half-planes having boresight 0° or 180°. Process control then flows to step 2148 where the gain and/or phase differences for the elements 60 are set to produce a beamwidth within the quadrant $X - 90^\circ$ to X° having a boresight direction along the centre of that quadrant, as shown in Figure C6 with the boresight direction X set to be $X - 45^\circ$. At step 2150, the received signal strength output from the rake receiver is measured and stored as value MX. At step 2152 it is determined whether or not MX is greater than N. If the result of step 2152 is "yes" then the process control flows to step 2160, otherwise process control flows to step 2154 where the gain and/or phase differences of element 60 are set for a beamwidth from X to $X + 90^\circ$ as shown in Figure C7 with a boresight direction in the centre of the quadrant, such that $X = X + 45^\circ$. At step 2156, the received signal strength output from the RAKE receiver is measured and stored as value MX. At step 2158, it is determined whether or not MX is greater than N. If the result at step 2158 is "no", then the process control flow returns to step 2106, otherwise process control flows to step 2160 where N is set to equal MX. At step 2160, process flow control originates from either step 2158, 2152 or 2144.

[0091] Process control flows from step 2160 to step 2162 where it is determined whether or not there has been a change in base station or a change in the spreading sequence for communication with the base station 102. If the result at step 102 is "yes" then process control returns to step 2106 and the setup process restarts. If the result of step 2162 is "no", then process control flows to step 2164 where it is determined whether or not a SID frame or end-of-packet frame is present in the received data. If the result of step 2164 is "no" then process control returns to step 2162, otherwise, process control flows to step 2166 where the antenna boresight direction X is reset to be $X = X - 30^\circ$ and the received signal strength output from the rake receiver is measured at step 2168, and the value stored with the label MX-30. Process control then flows to step 2170 where it is determined whether the value stored under the label MX-

30 is greater than N. If the answer is "yes", then at step 2172, N is set to equal the value corresponding to label MX-30. For a result "no", then at step 2174, the antenna boresight direction X is set to be $X=X+30^\circ$, and at step 2176, the received signal strength output from the RAKE receiver is measured and stored under label MX+30. Next, at step 2178, it is determined whether the value stored under label MX+30 is greater than N. If the answer at step 2178 is "yes", then at step 2180, N is set equal to the value corresponding to MX+30 and process control flows to step 2162. If the answer is "no", then at step 2182, the antenna boresight direction is set to be equal to $X=X-30$ and process control flows to step 2162.

[0092] As can be seen from the flowcharts, steps 2102 to 2160 comprise the antenna beam setup process, and step 2162 to 2182 comprise the steps for tracking the optimum antenna beam direction.

[0093] In another Example in accordance with a further aspect of the present invention, a directional sensor 70 is included in the handset 50 of mobile station 102. Sensor 70 is a directional sensor capable of determining a change in azimuthal orientation relative to a starting point. As illustrated in Figure 5, sensor 70 is coupled to microprocessor 406, which receives signals indicative of a change in azimuthal orientation determined by the directional sensor. Microprocessor 406 is operable to receive the signals from sensor 70 and to process them in order that they may be utilised in accordance with an embodiment of the invention for assisting in determining an appropriate beam pattern for receiving an optimum signal. The process for setting up and controlling a steerable antenna in a CDMA system, for a MS 102 including a sensor 70 is illustrated in the flowchart of Figure 22. Since many of the steps illustrated in the flowchart of Figure 22 are the same as for the flowchart of Figure 21, like references will be used to identify like steps.

[0094] Referring now to Figure 22, after the control process has been initiated at step 2102, the antenna boresight direction X is set to equal D_{T0} which is the orientation of the MS 102 determined by the sensor 70 at a reference time, time 0. Having determined the reference direction by means of a sensor 70, the process flows from step 2106 through to step 2160 in the manner as described with reference to Figure 21. However, after step 2160, another orientation reading is taken at step 2104. The new direction is designated D_{T1} , and the change in orientation, Rd is given by the following equation, $Rd=|(D_{T1}-D_{T0})|$. At step 2162, it is determined whether or not there has been a change in the base station, a change in spreading sequence or whether the change in orientation, Rd, is greater than 60° . If the result at step 2162 is "yes" then process control returns to step 2106 where setup of the steerable beam antenna is restarted. If the result of step 2162 is "no", then at step 2206, the antenna boresight direction X is set to be $X=X-(D_{T1}-D_{T0})$. Step 2206 takes into account the effect of the change in orientation as measured by sensor 70 in

order that the antenna beam pattern is still directed onto an optimum receive signal direction.

[0095] Steps 2164 to 2182 are executed in accordance with the correspondingly referenced steps of flowchart illustrated in Figure 21.

[0096] Although the use of a sensor 70 for identifying changes in orientation has been described with reference to a CDMA system, it will be evident to a person of ordinary skill in the art, that the same may be utilised for a "TDMA" system such as the GSM system, and incorporated in the flowchart illustrated in Figure 11 at suitable points. Optionally, sensor 70 may comprise an electronic compass and be capable of indicating an absolute direction with reference to magnetic north.

[0097] Embodiments of the invention may be enhanced by decoding the BCCH of base stations proximal to the current base station during the steps of measuring the signal strength. The strengths of the signals from the proximal base stations may be utilised to identify their position relative to the current base station, such information can then assist in prompt handover and beam formation for optimum signal with the new base station.

[0098] In view of the foregoing description it will be evident to a person skilled in the art that various modifications may be made within the scope of the invention. For example, although embodiments of the invention have been described with reference to a mobile station, embodiments of the invention may equally be incorporated in base stations. For such embodiments operable in a CDMA system, the delays in the RAKE receiver of the base station may be utilised to form respective antenna beams for communication with mobile stations using respective communication channels.

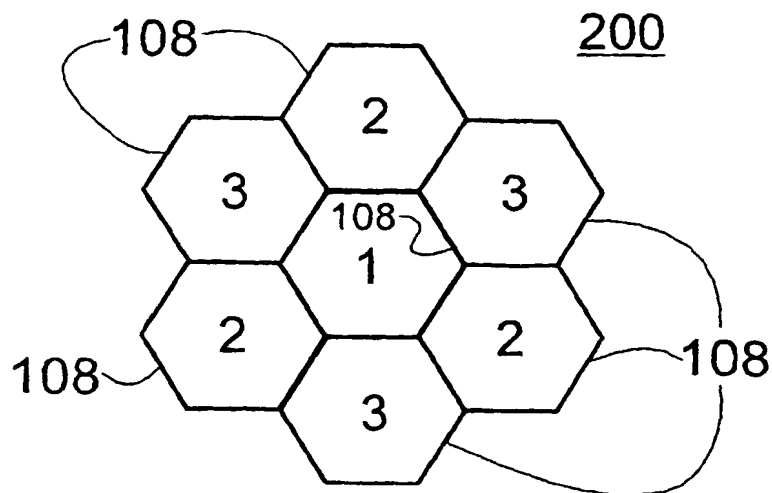
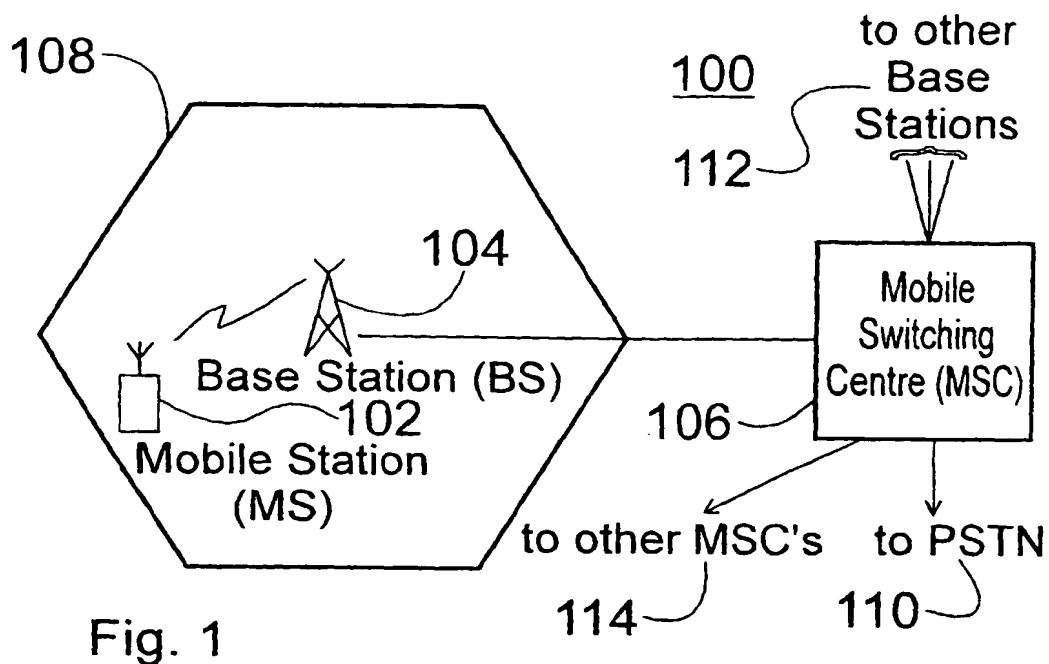
[0099] The scope of the present disclosure includes any novel feature or combination of features disclosed therein either explicitly or implicitly or any generalisation thereof irrespective of whether or not it relates to the claimed invention or mitigates any or all of the problems addressed by the present invention. The applicant hereby gives notice that new claims may be formulated to such features during the prosecution of this application or of any such further application derived therefrom. In particular, with reference to the appended claims, features from dependent claims may be combined with those of the independent claims and features from respective independent claims may be combined in any appropriate manner and not merely in the specific combinations enumerated in the claims.

Claims

1. Radio apparatus for a radio communications system, the radio apparatus comprising:

means for determining a period of inactivity for said radio apparatus; and

- means for determining signal quality of a signal received during said period of inactivity.
2. Radio apparatus according to Claim 1, further comprising:
 - a directional beam antenna; and
 - steering means for determining and steering said antenna beam to an optimum beam direction in accordance with said signal quality determined by said means for determining signal quality.
 3. Radio apparatus according to Claim 1 or 2, said signal received during said period of inactivity comprising a broadcast signal.
 4. Radio apparatus according to Claim 3 operable for a cellular radio communications system, said broadcast signal comprising a signal from a base station with which said radio apparatus is in primary communication.
 5. Radio apparatus according to Claim 3 or 4 operable for a cellular radio communications system, said broadcast signal comprising a signal from any one of one or more base stations for cells adjacent the cell defined by said base station with which said radio apparatus is in primary communication.
 6. Radio apparatus according to any preceding Claim, wherein said period of inactivity comprises a period determined as being designated for the transmission and/or reception of redundant information.
 7. Radio apparatus according to any preceding Claim operable for speech communication, said period of inactivity comprising non-active segments during transmission and/or reception of silence identity (SID) information.
 8. Radio apparatus according to claim 7, said non-active segments comprising an empty frame and/or part thereof during transmission of SID frames.
 9. Radio apparatus according to any preceding Claim operable to transmit data, said period of inactivity comprising a period subsequent to an end of data signal transmitted and/or received by said radio apparatus.
 10. A method for operating radio apparatus, comprising:
 - determining a period of inactivity for said radio apparatus; and
 - determining signal quality of a signal received during said period of inactivity.
 11. A method according to Claim 10, further comprising steering an antenna beam to an optimum beam direction in accordance with said signal quality.
 12. A method according to Claim 10 or 11, said signal comprising a broadcast signal.
 13. A method according to Claim 12 operable for a cellular radio communications system, said broadcast signal comprising a signal from a base station with which said radio apparatus is in primary communication.
 14. A method according to Claim 12 operable for a cellular radio communications system, said broadcast signal comprising a signal from any one of one or more base stations for cells adjacent the cell defined by said base station with which said radio apparatus is in primary communication.
 15. A method according to Claim 14, further comprising determining and storing optimum beam directions for said signal from any one of one or more base stations, for utilisation during a subsequent hand-over operation to a one of said one or more base stations.
 16. A method according to any one of Claims 10 to 15, further comprising determining a period designated for transmission and/or reception of redundant information for said radio apparatus.
 17. A method according to any one of Claims 10 to 16 for speech communications, further comprising determining a non-active segment during transmission and/or reception of silence identity (SID) information.
 18. A method according to Claim 17, said non-active segment comprising empty frames and/or part thereof during transmission and/or reception of SID frames.
 19. A method according to any one of claims 10 to 18, for data communications, further comprising determining an end of data signal transmitted and/or received by said radio apparatus.
 20. A radio communications device comprising radio apparatus according to any one of claims 1 to 9 or operable in accordance with any one of claims 10 to 19, further comprising a user interface including a display, a keypad or keyboard for inputting data and/or commands to said communications device, a transceiver and a directional beam antenna.
 21. A radio telephone comprising a radio communications device according to claim 20.



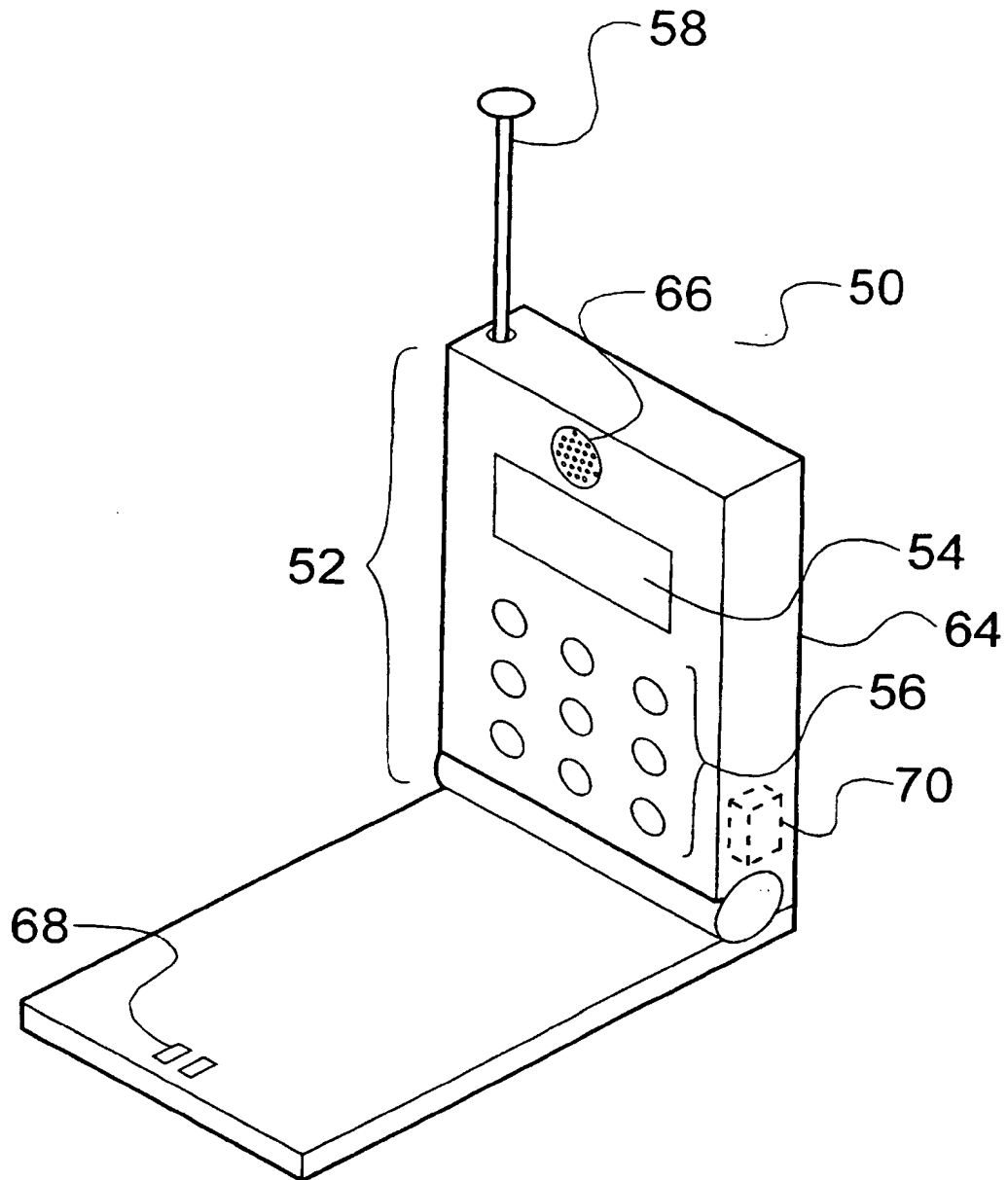


Fig. 3

400

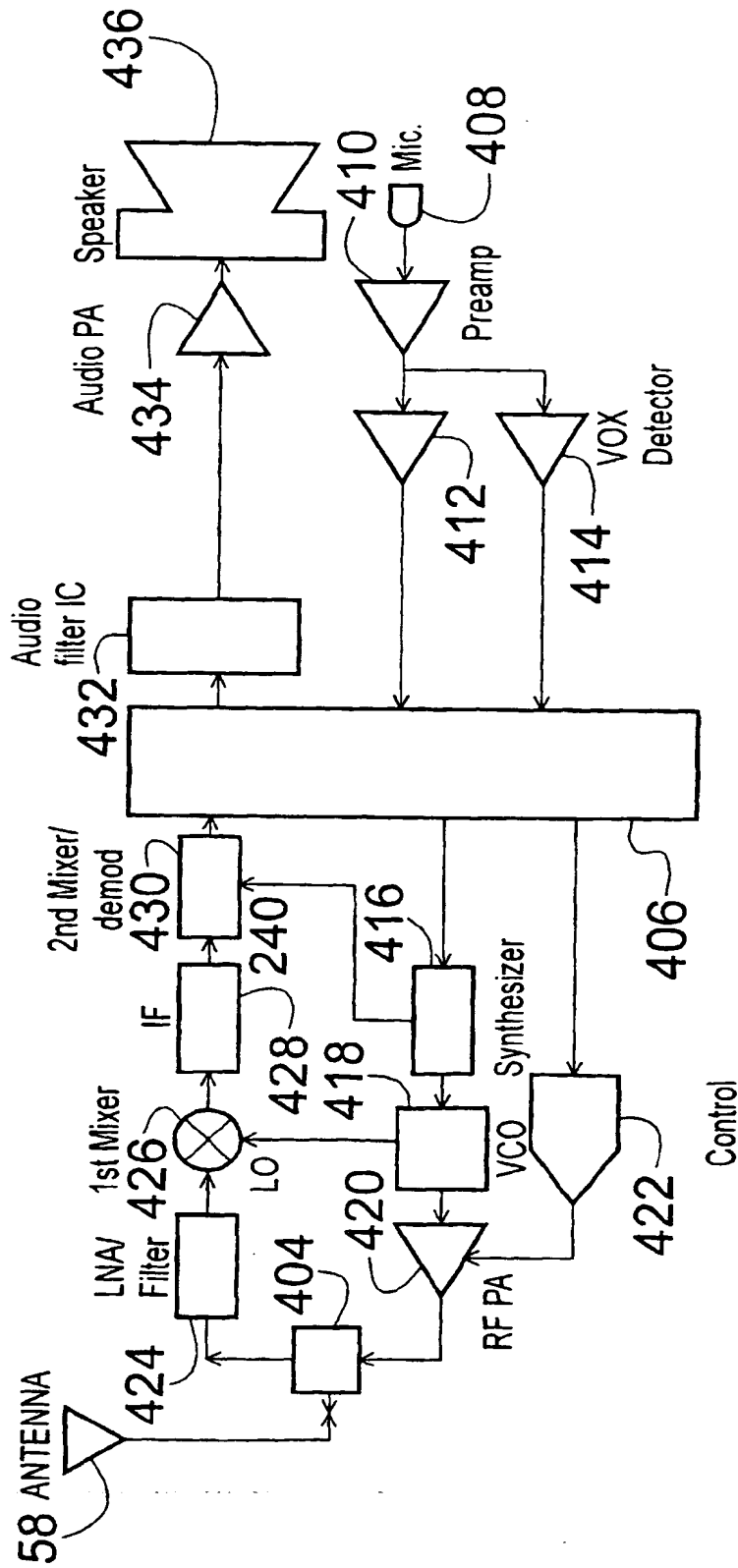


Fig. 4

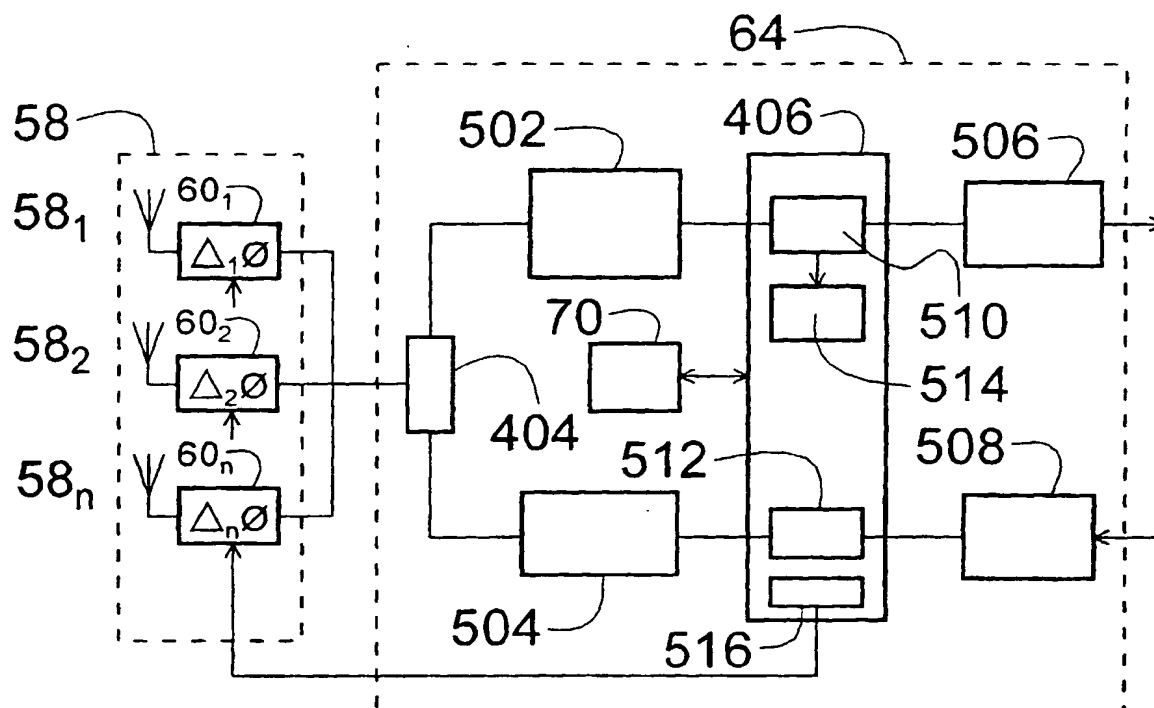


Fig. 5

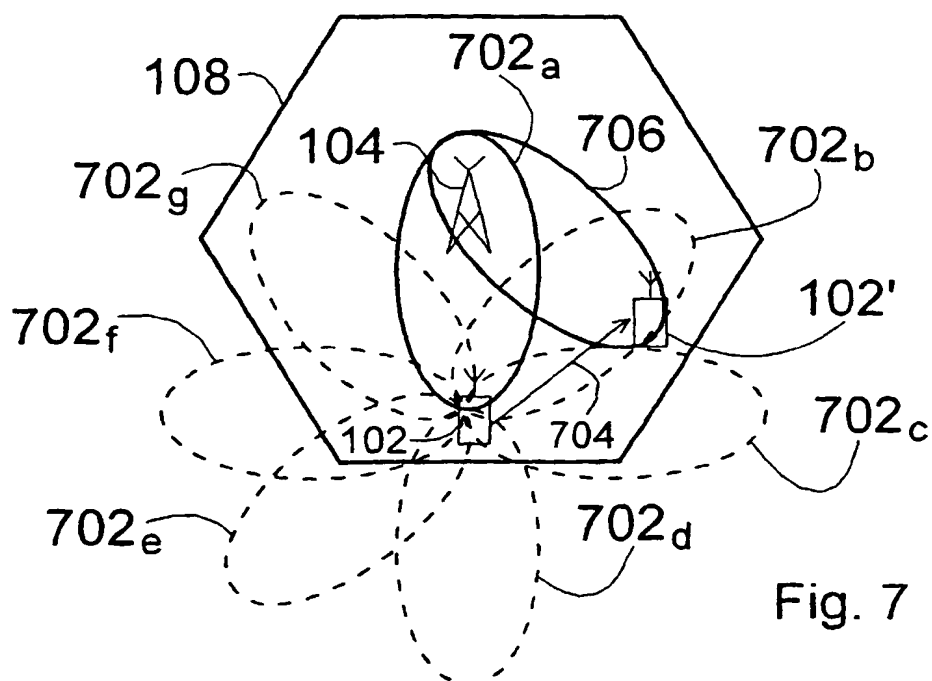


Fig. 7

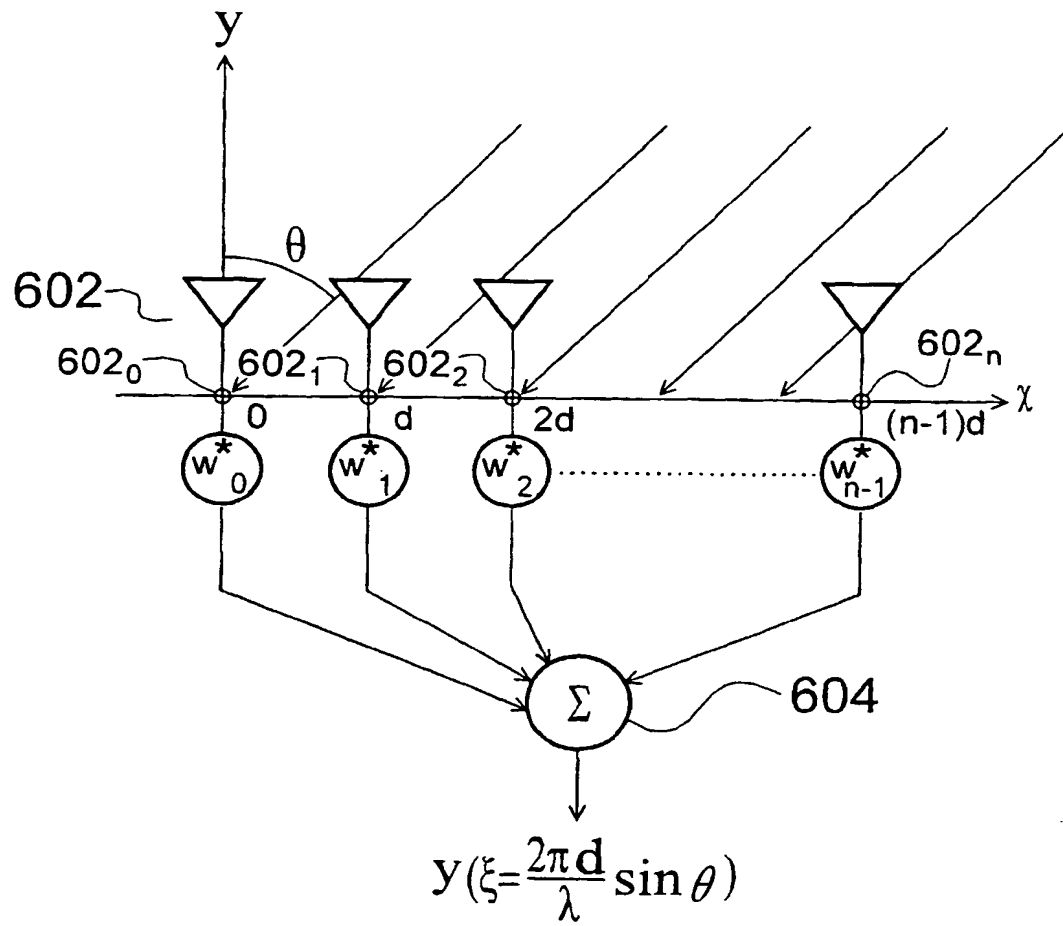


Fig. 6

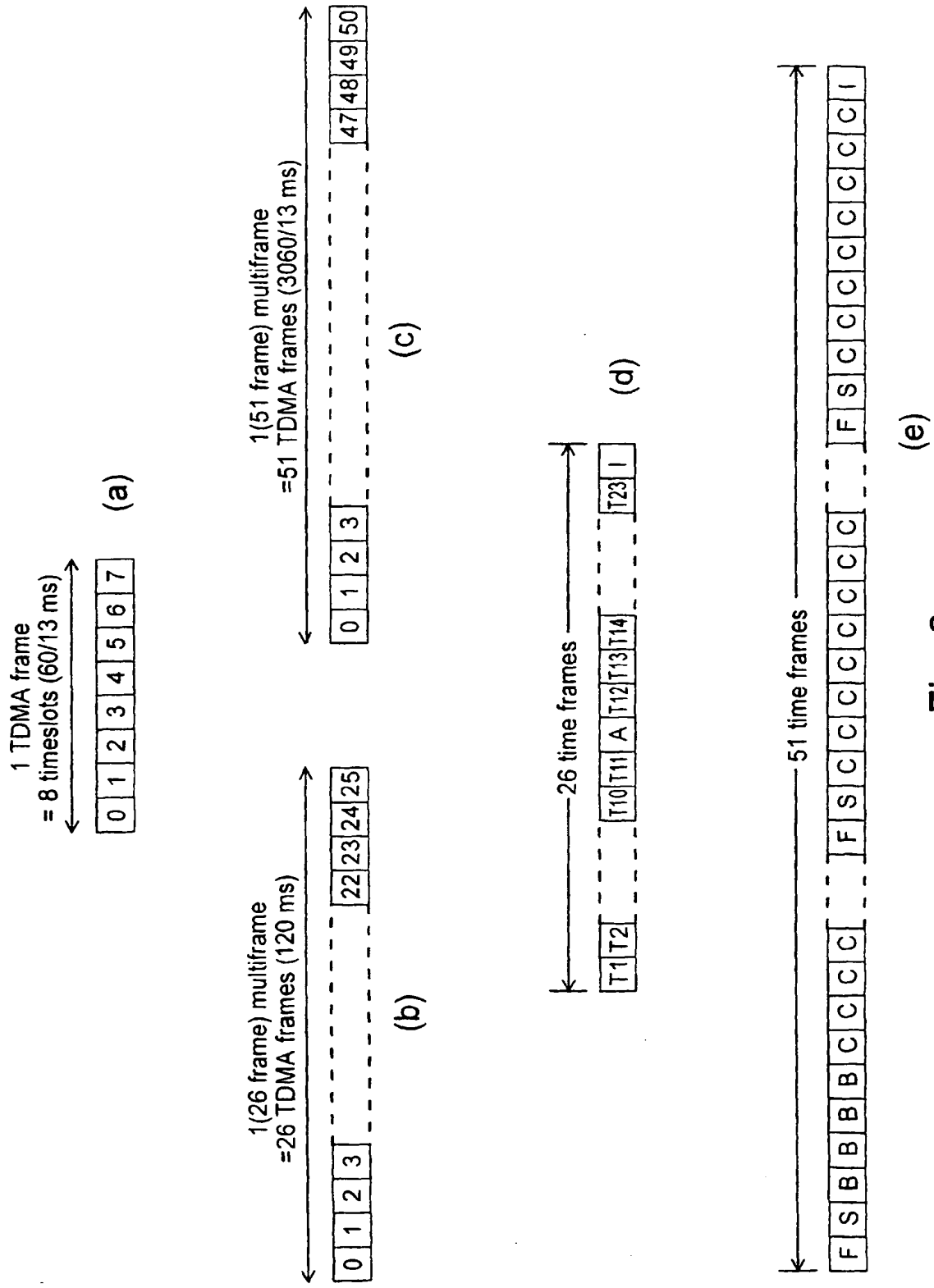


Fig. 8

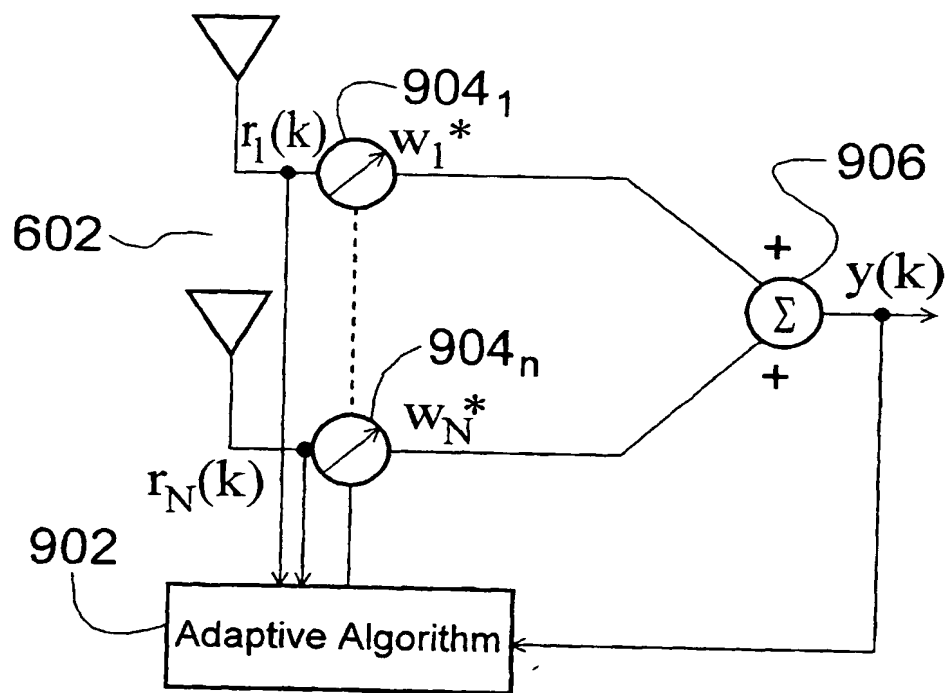


Fig. 9

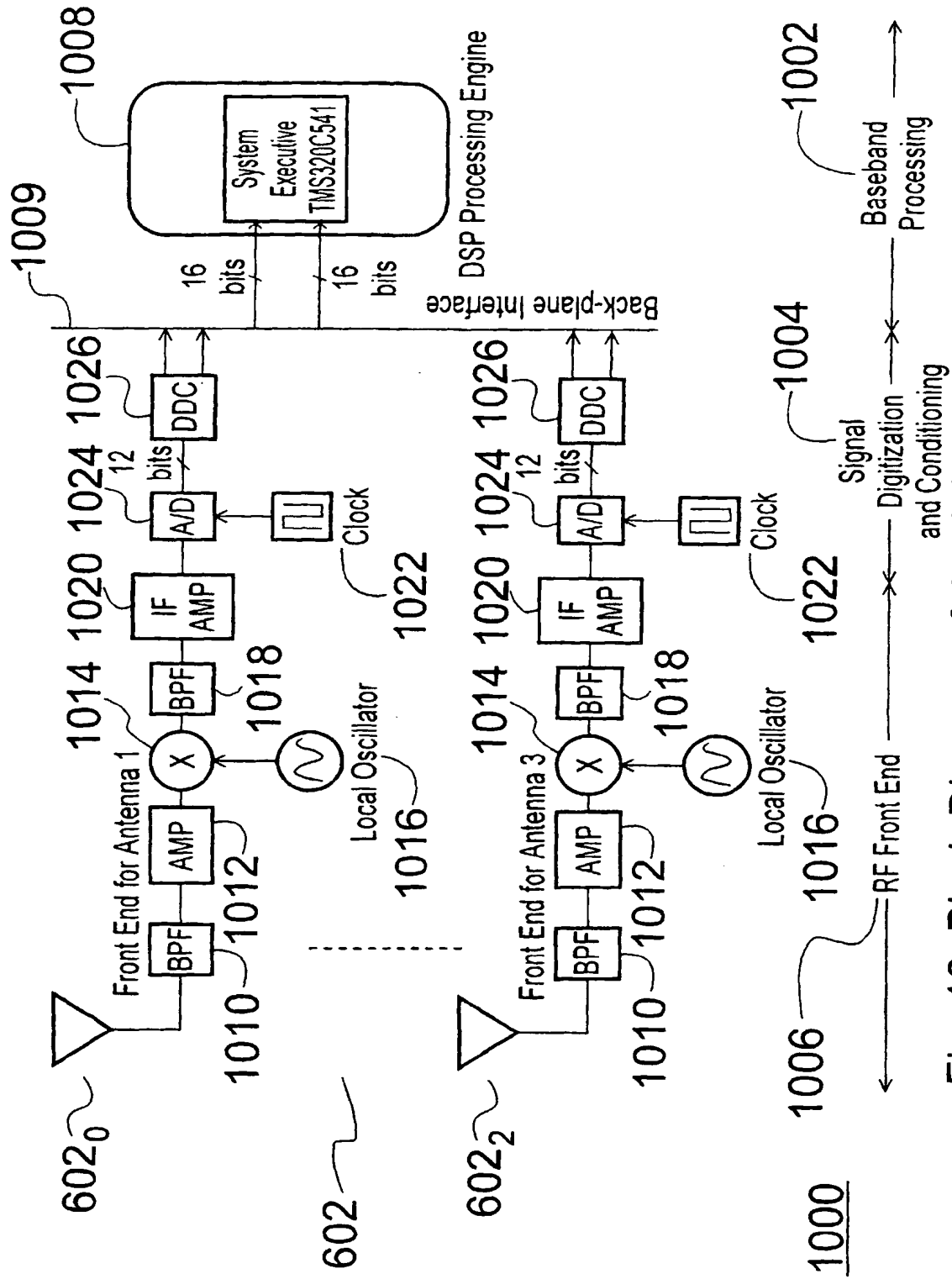


Fig. 10 Block Diagram of the Adaptive Array System

FLOW DIAGRAM FOR THE SET UP AND CONTROL OF THE STEERABLE ANTENNA

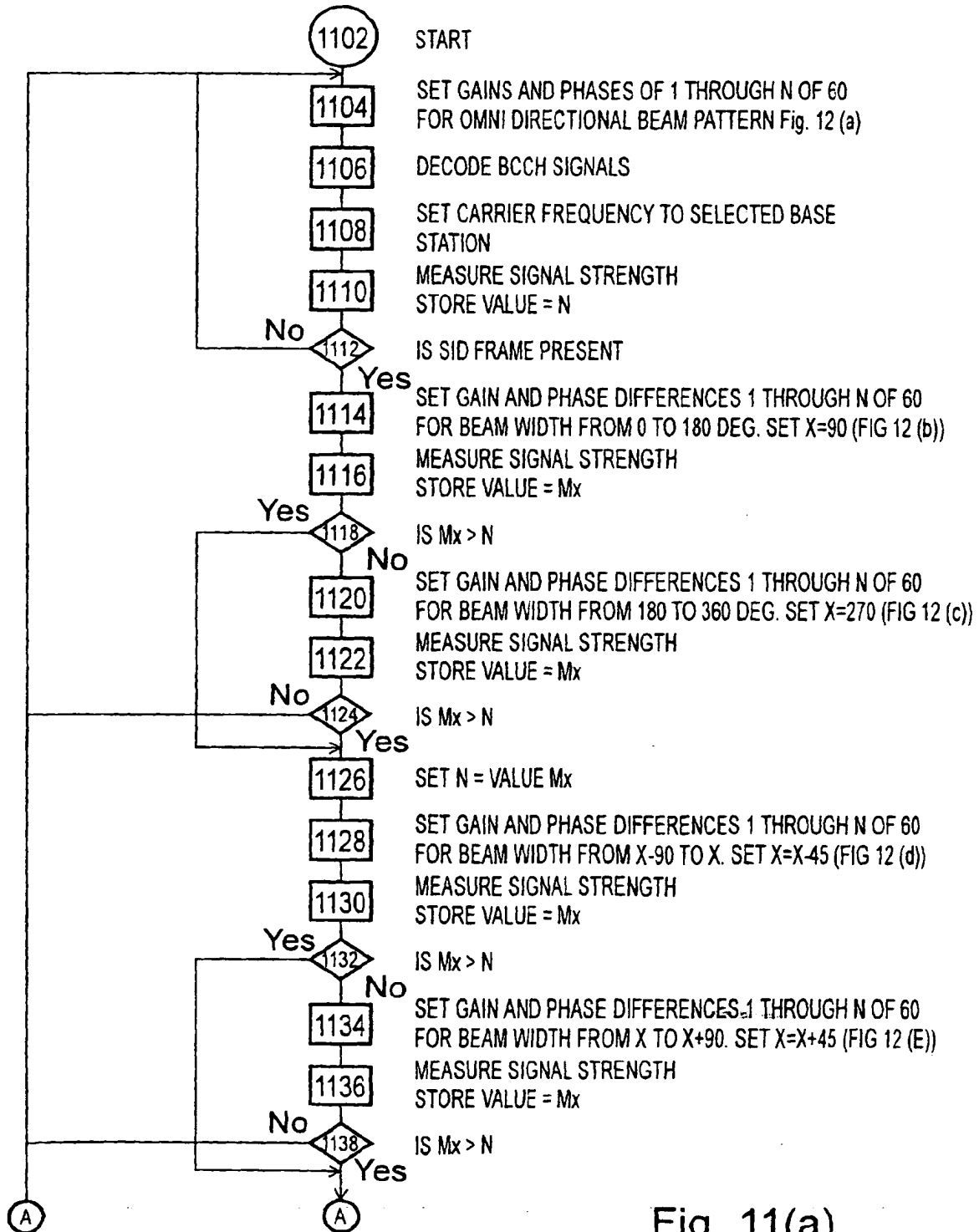


Fig. 11(a)

FLOW DIAGRAM FOR THE SET UP AND CONTROL OF THE STEERABLE ANTENNA

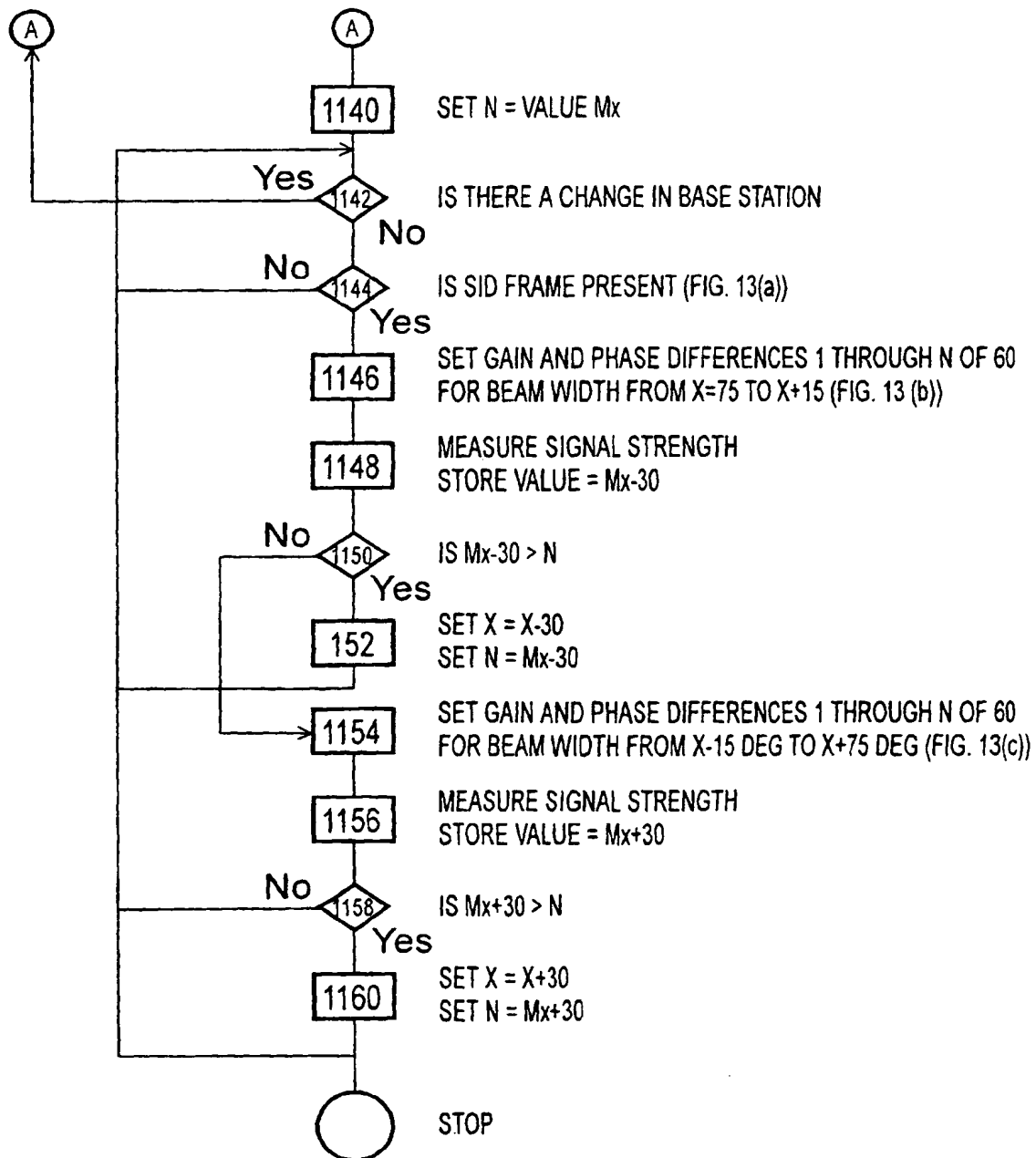
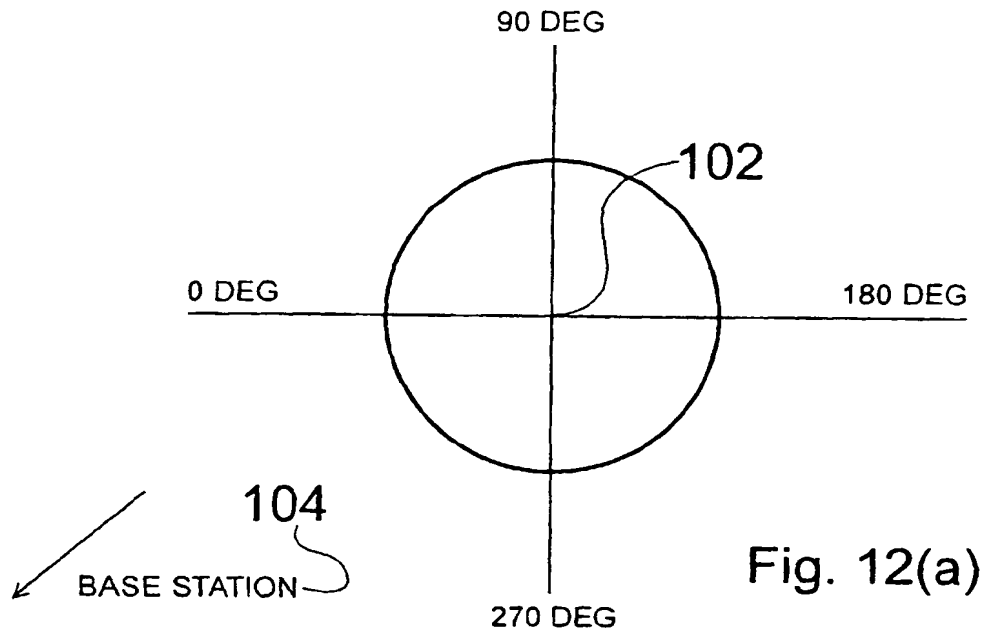
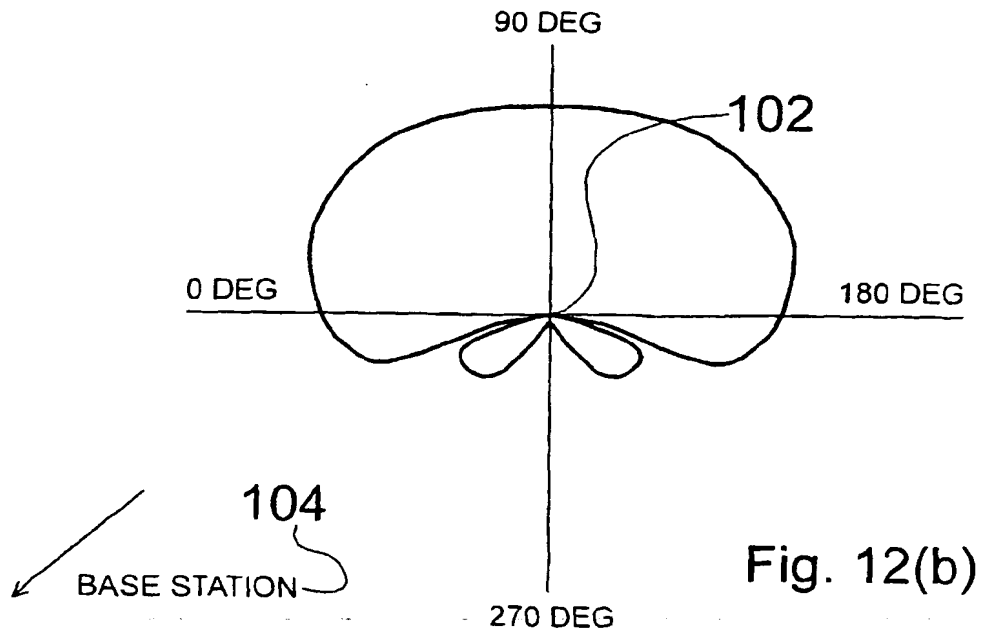


Fig. 11(b)

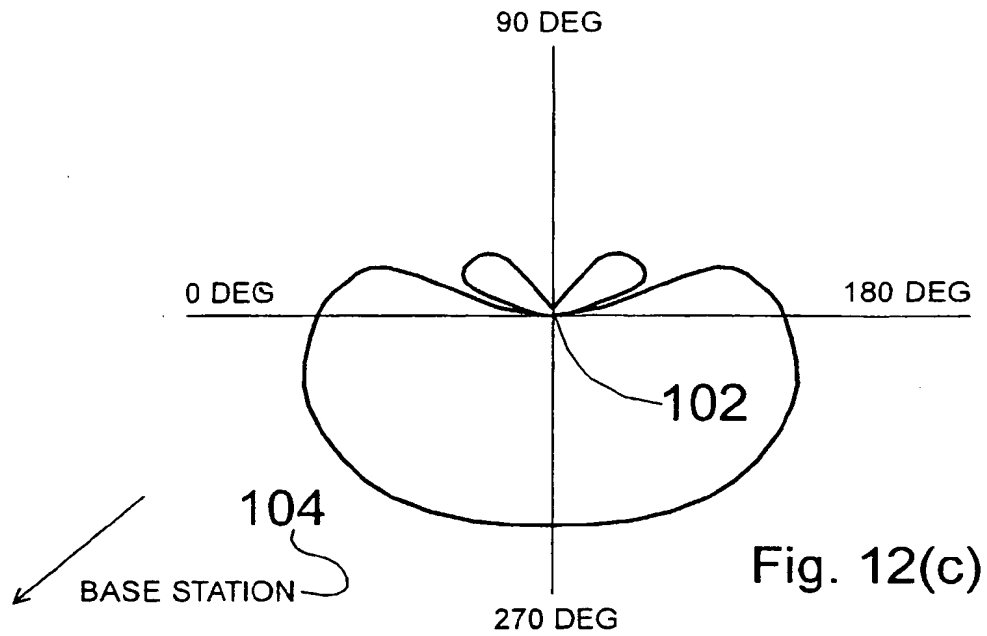
Beam Profile OMNI



Beam Profile 0-180 DEG.: X = 90



Beam Profile 180 - 360 DEG.: X = 270



Beam Profile X-90 TO X DEG.

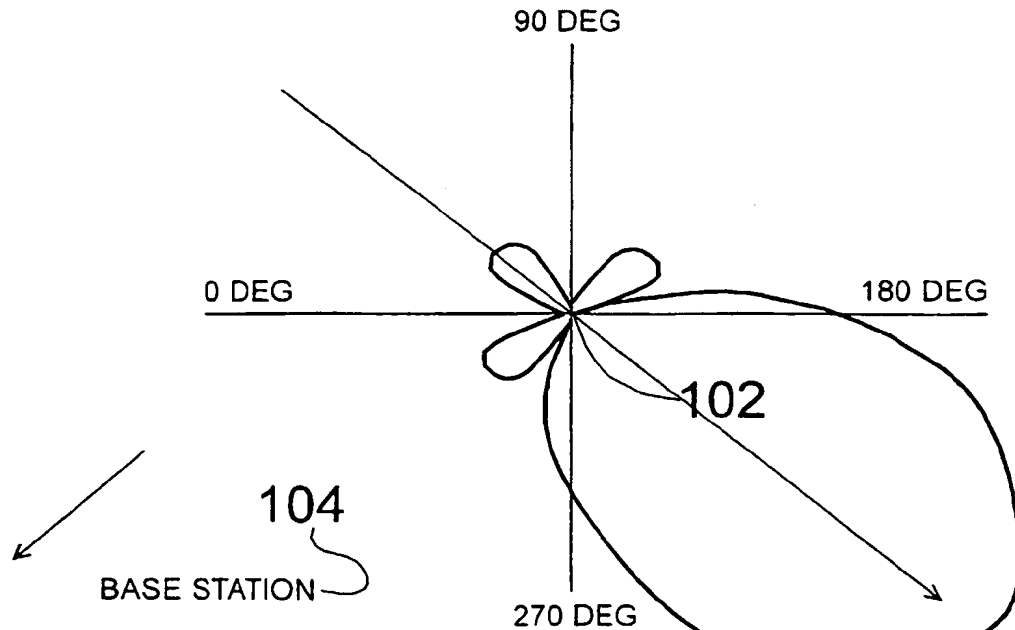


Fig. 12(d)

Beam Profile X TO X+90 DEG.

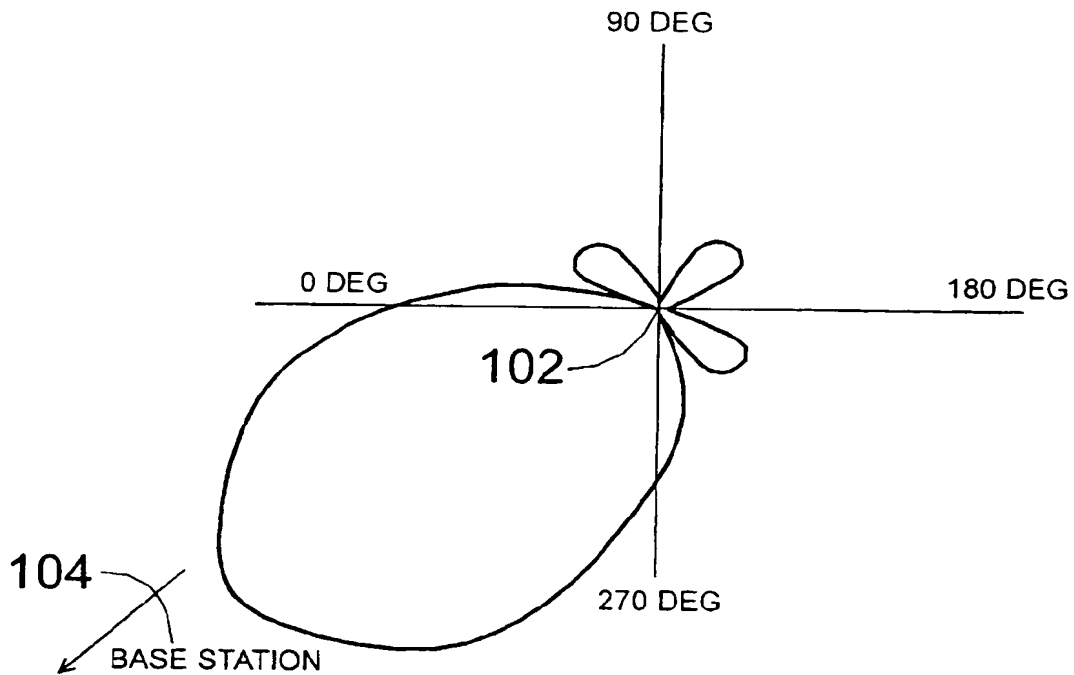


Fig. 12(e)

Beam Realignment (Step 1: Identify SID Frame)

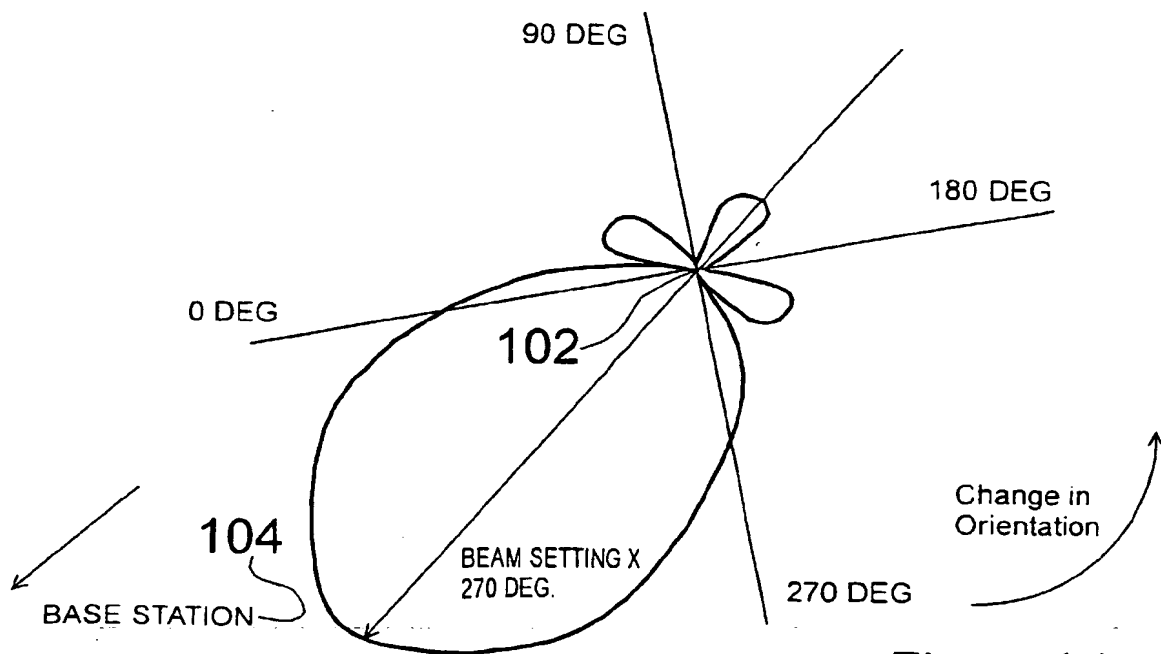


Fig. 13(a)

Beam Realignment (Step 2 Negative Swing)

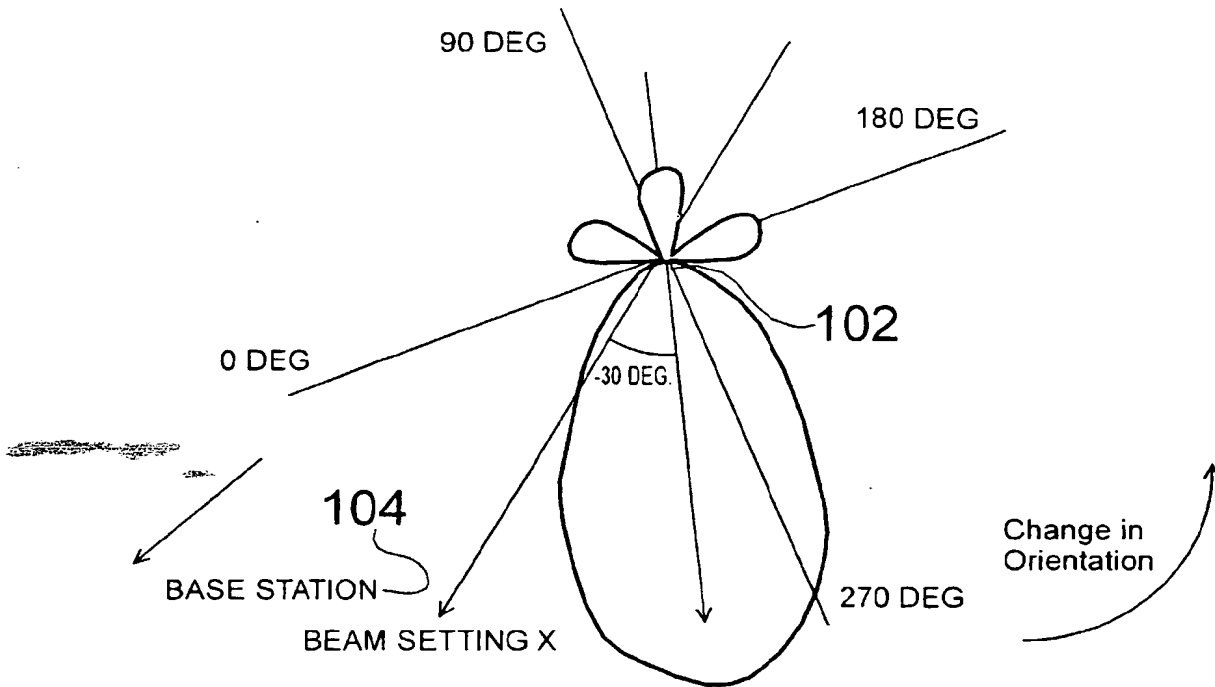


Fig. 13(b)

Beam Realignment (Step 3 Positive Swing)

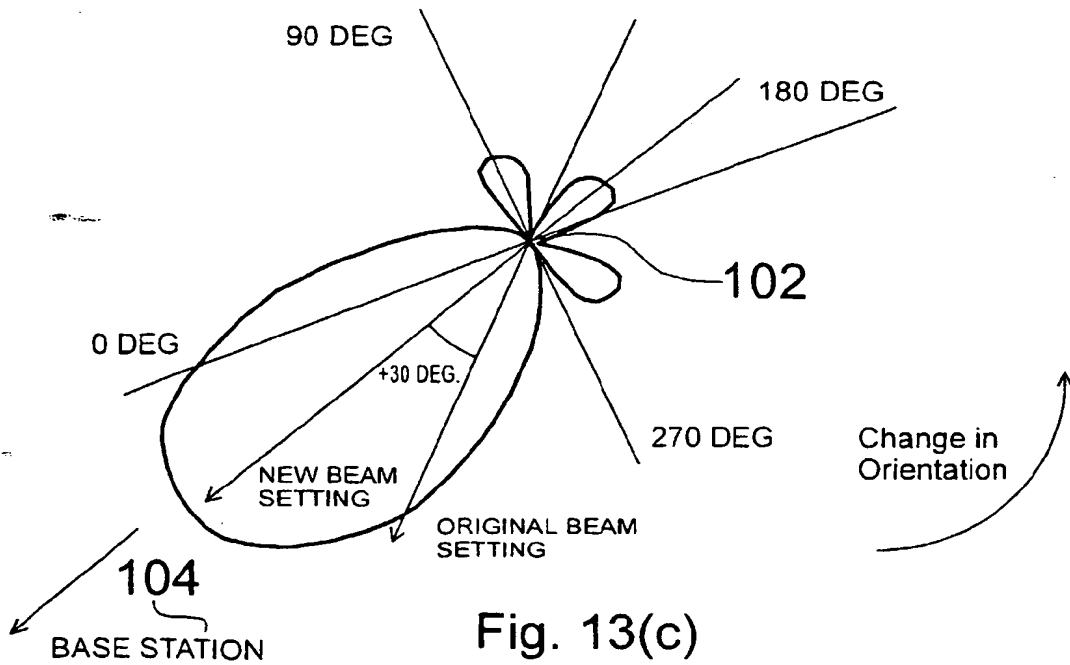


Fig. 13(c)

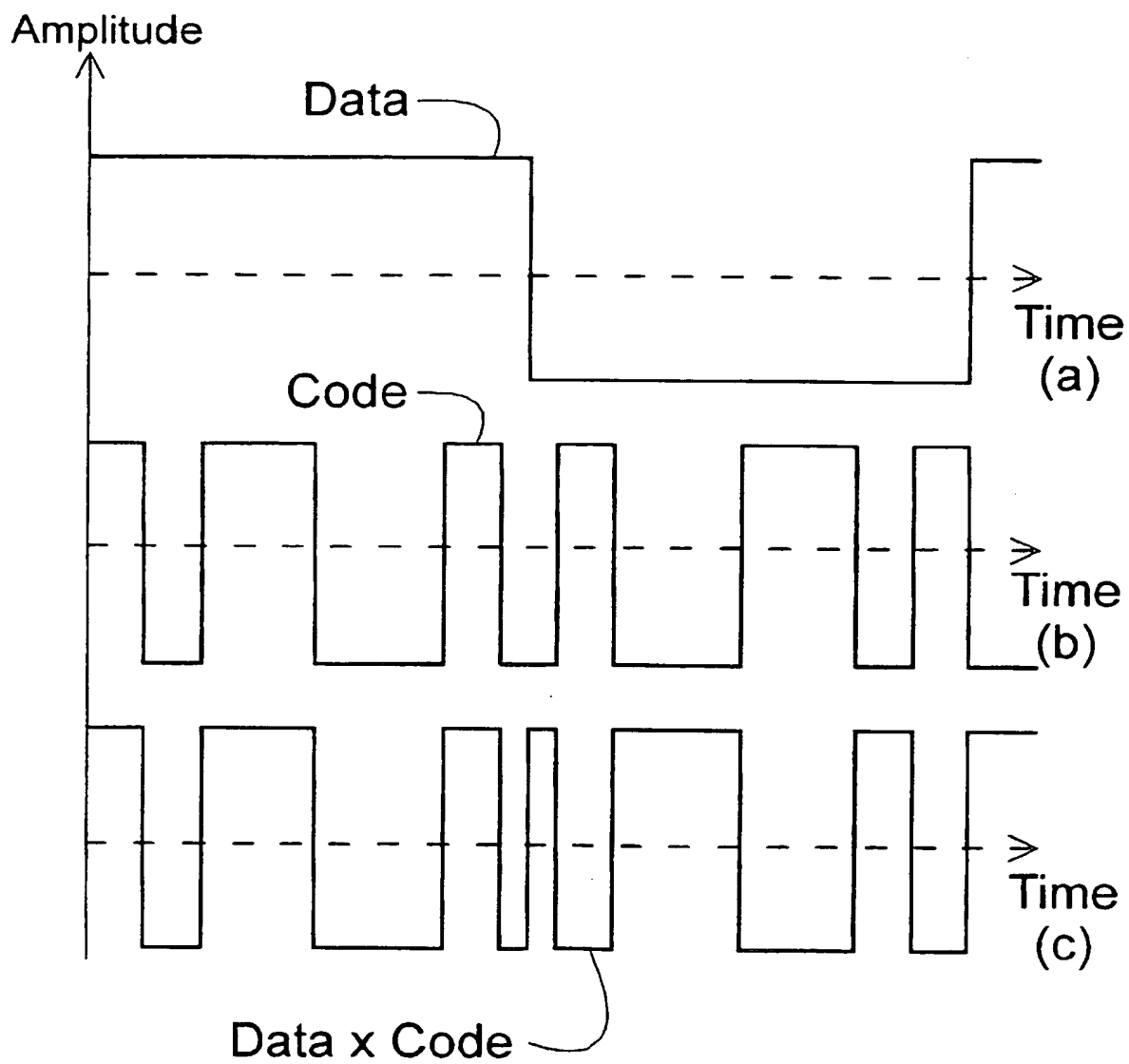


Fig. 14

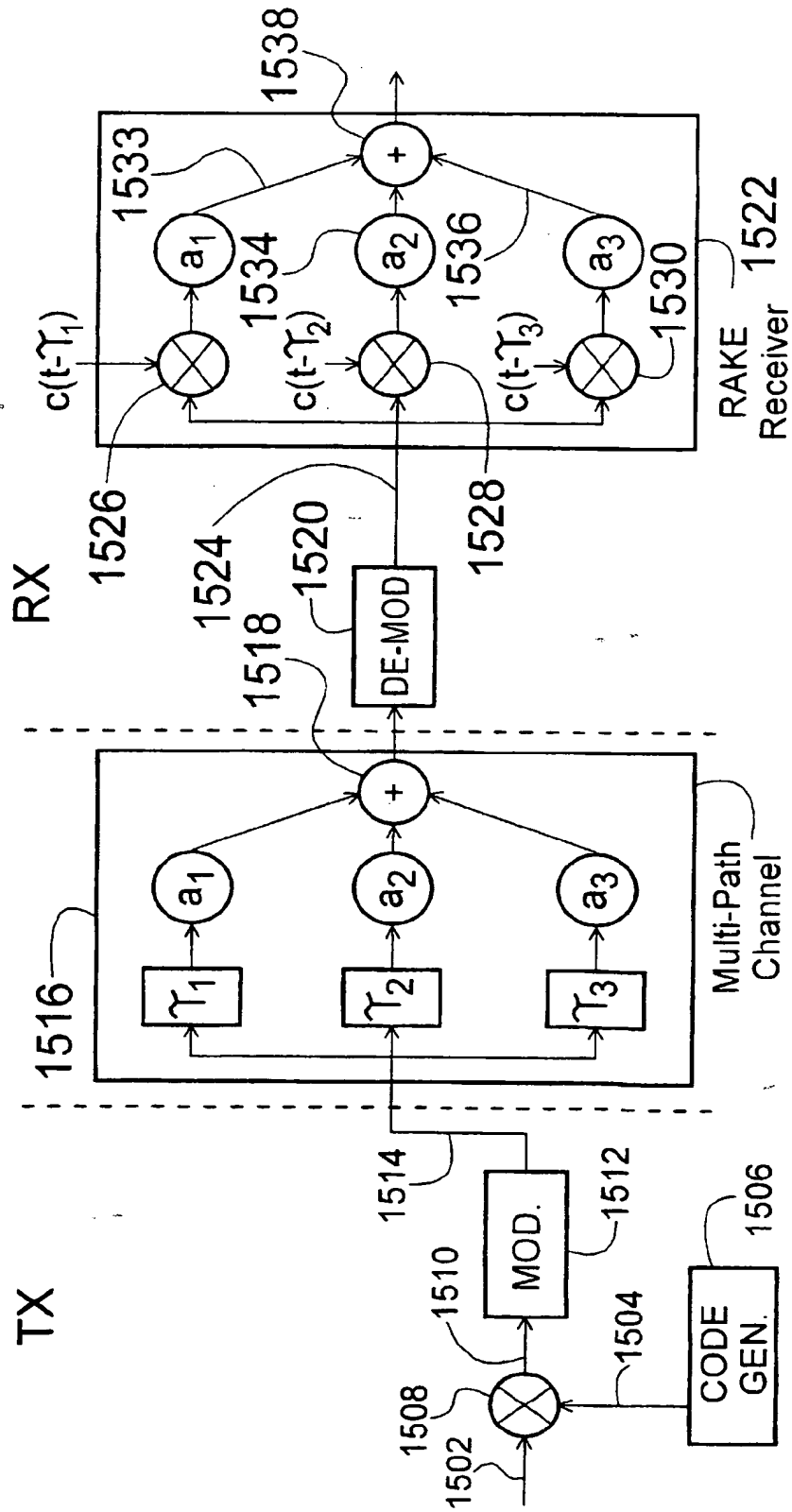


Fig. 15

Beam Pattern with T_2 T_1 & T_0 Approximately Equal

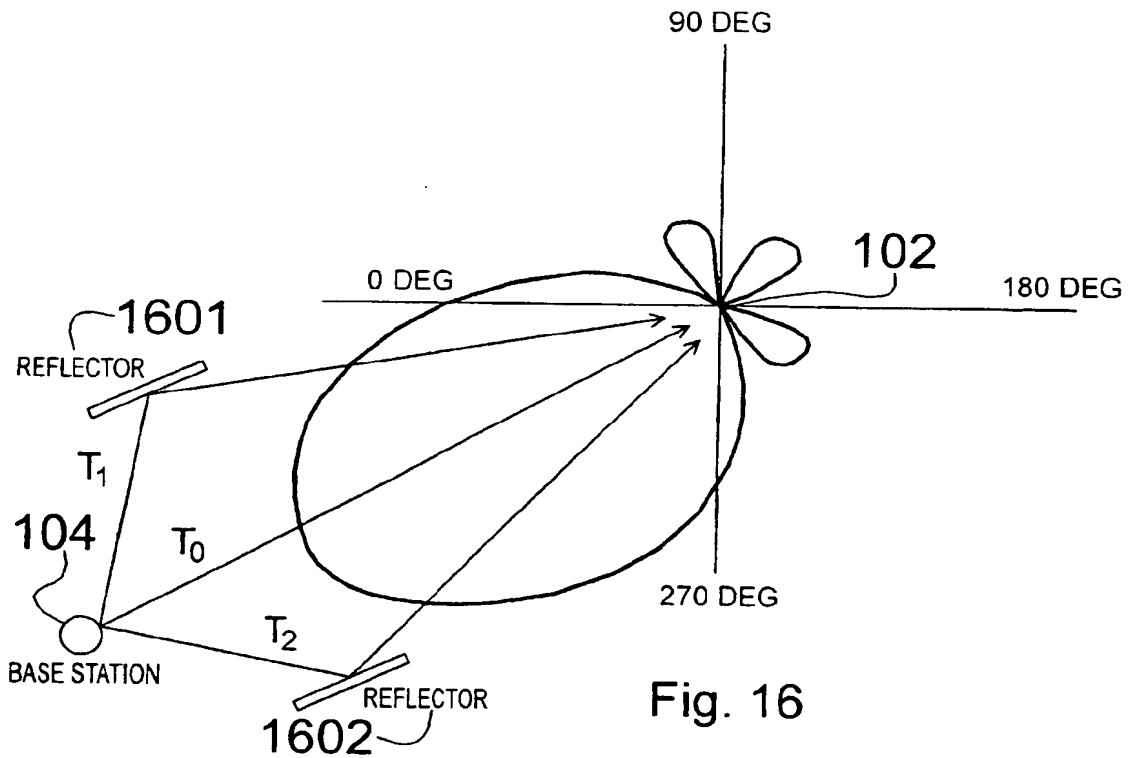


Fig. 16

Beam Pattern with T_2 T_1 & T_0 Similar

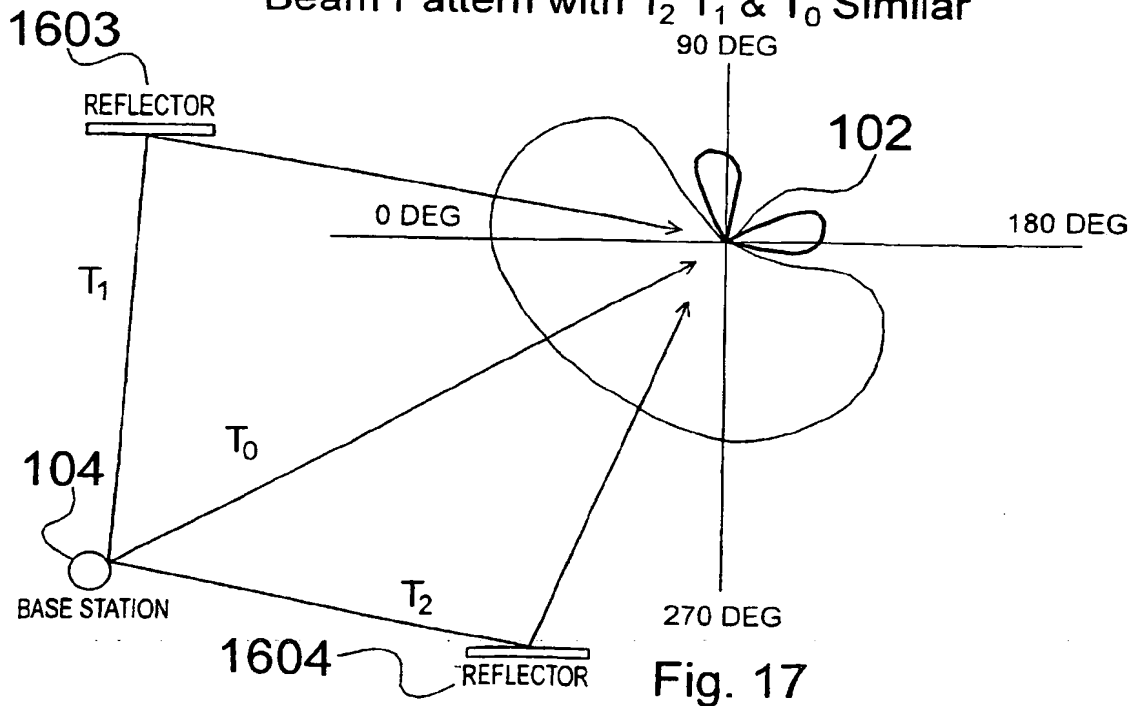


Fig. 17

Beam Pattern with $T_1 > T_2 > T_0$

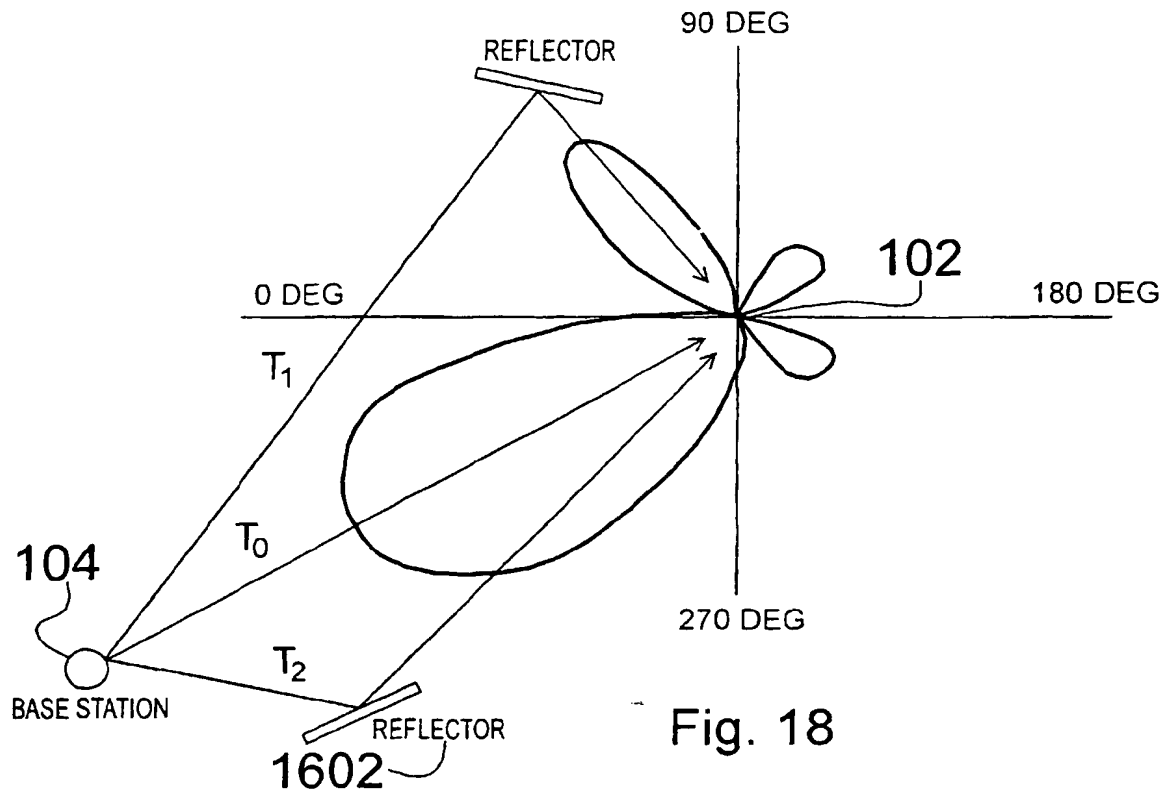


Fig. 18

Beam Pattern with $T_1 > T_2 > T_0$

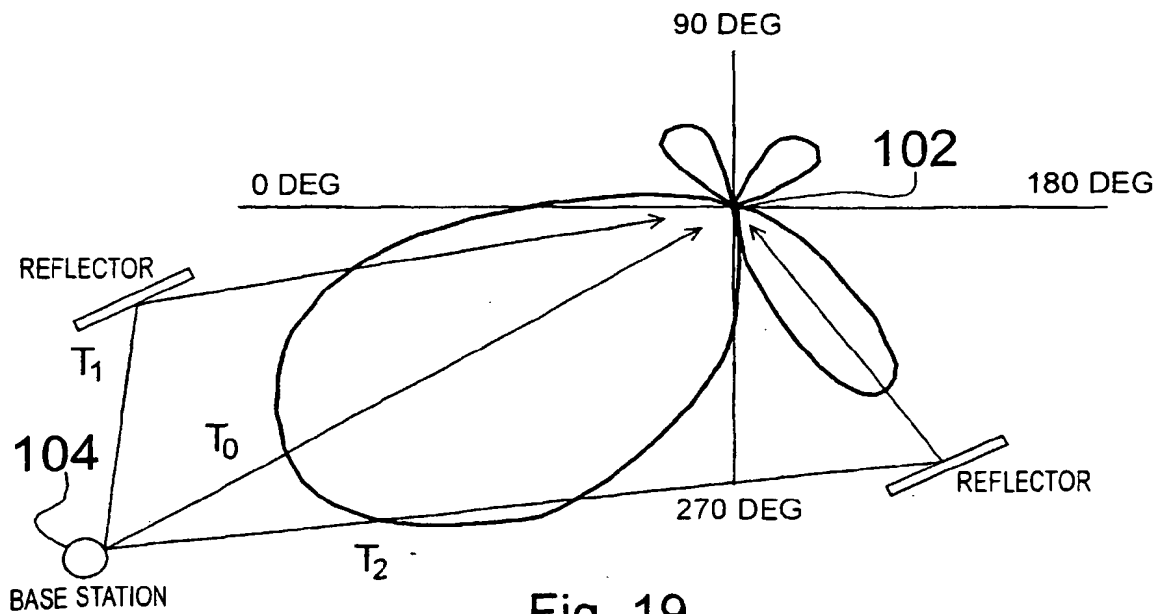


Fig. 19

Beam Pattern with T_1 & T_2 Similar and Larger than T_0

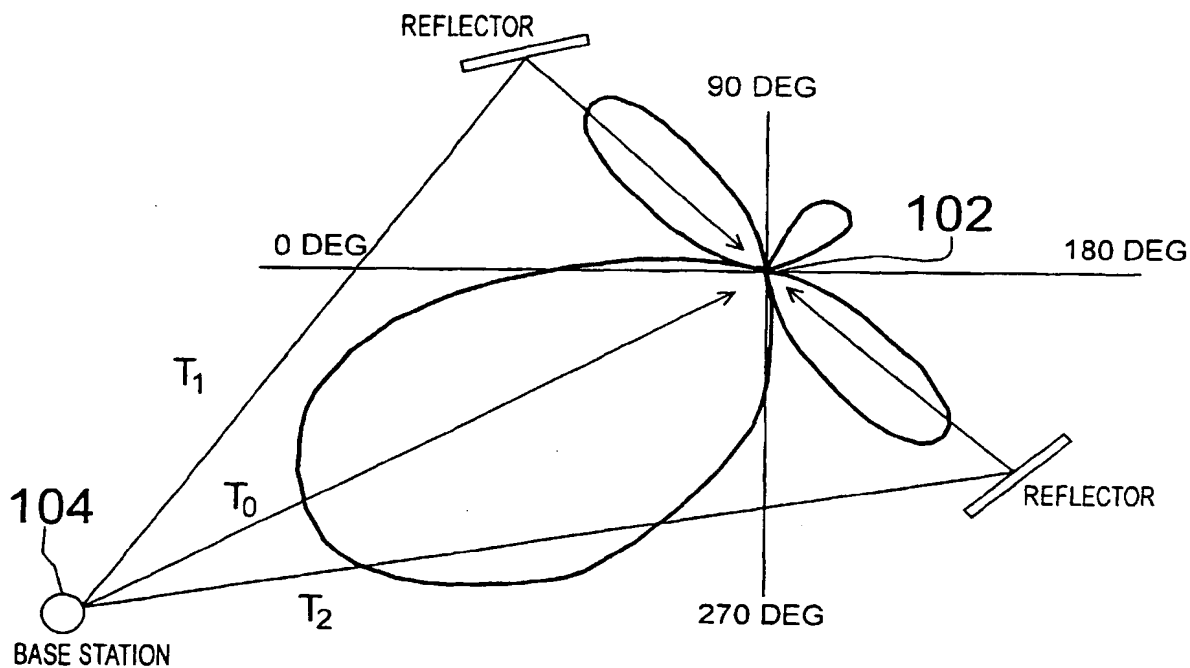


Fig. 20

FLOW DIAGRAM FOR SET UP AND CONTROL OF STEERABLE ANTENNA FOR CDMA SYSTEM

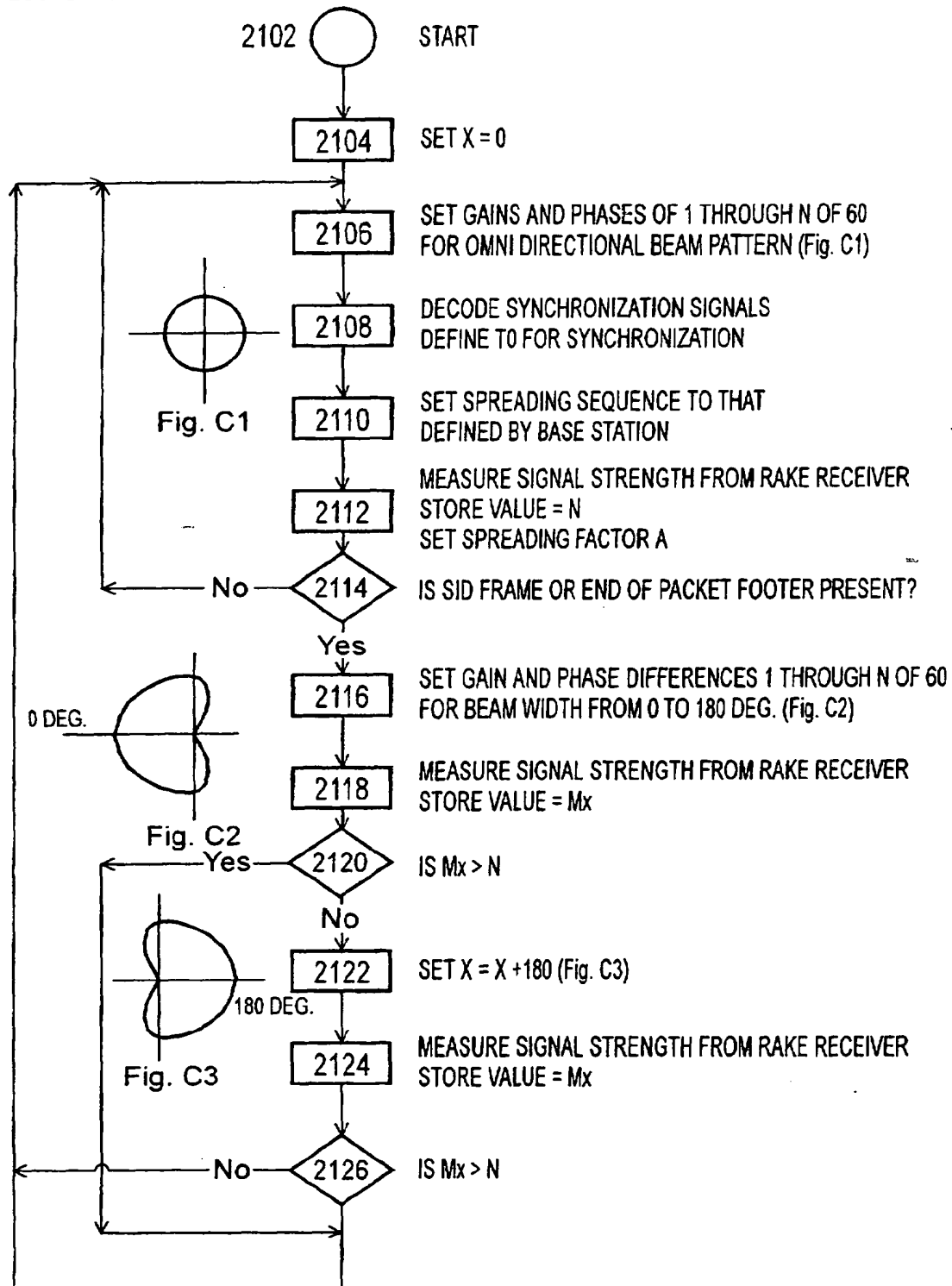


Fig. 21(a)

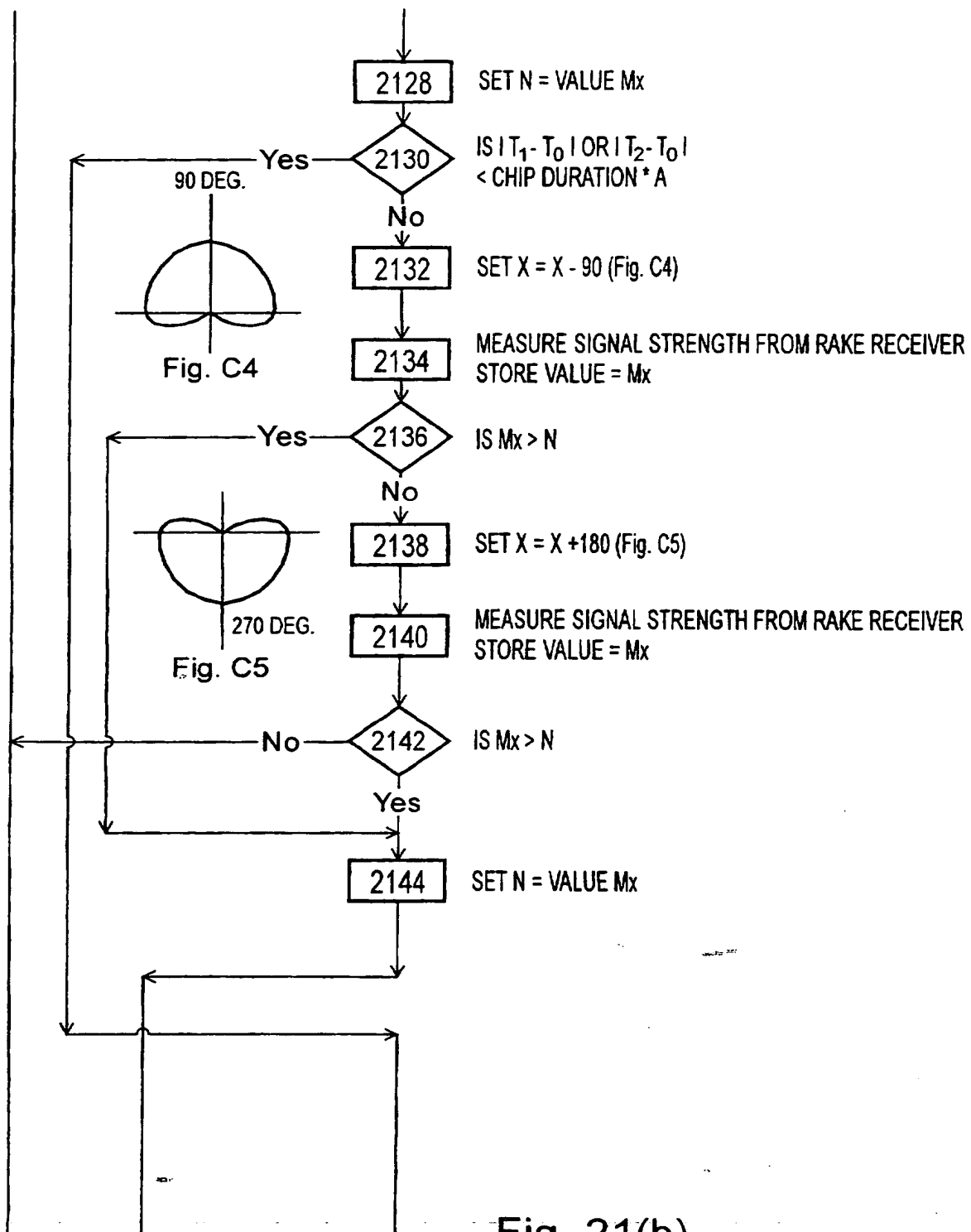


Fig. 21(b)

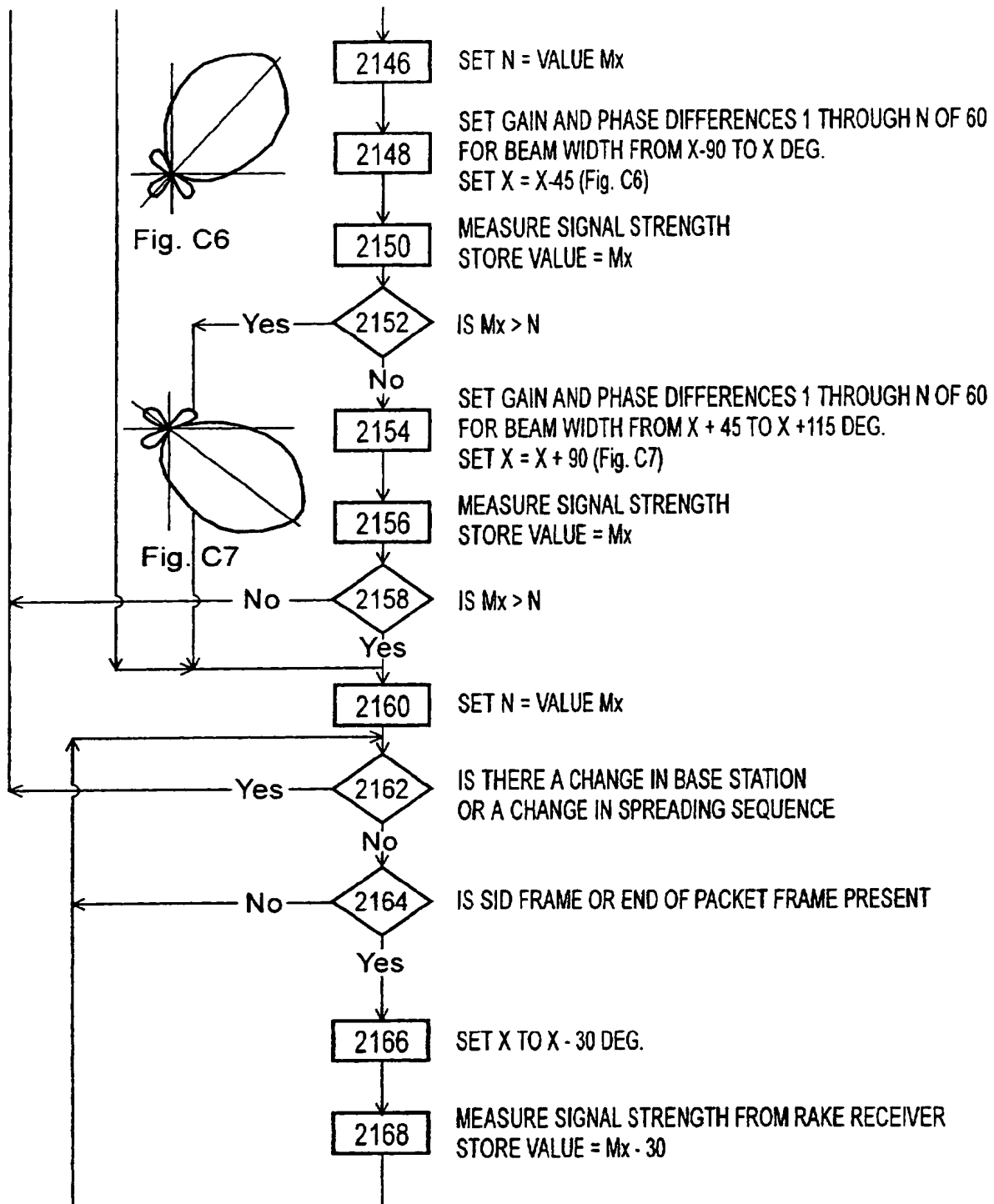


Fig. 21(c)

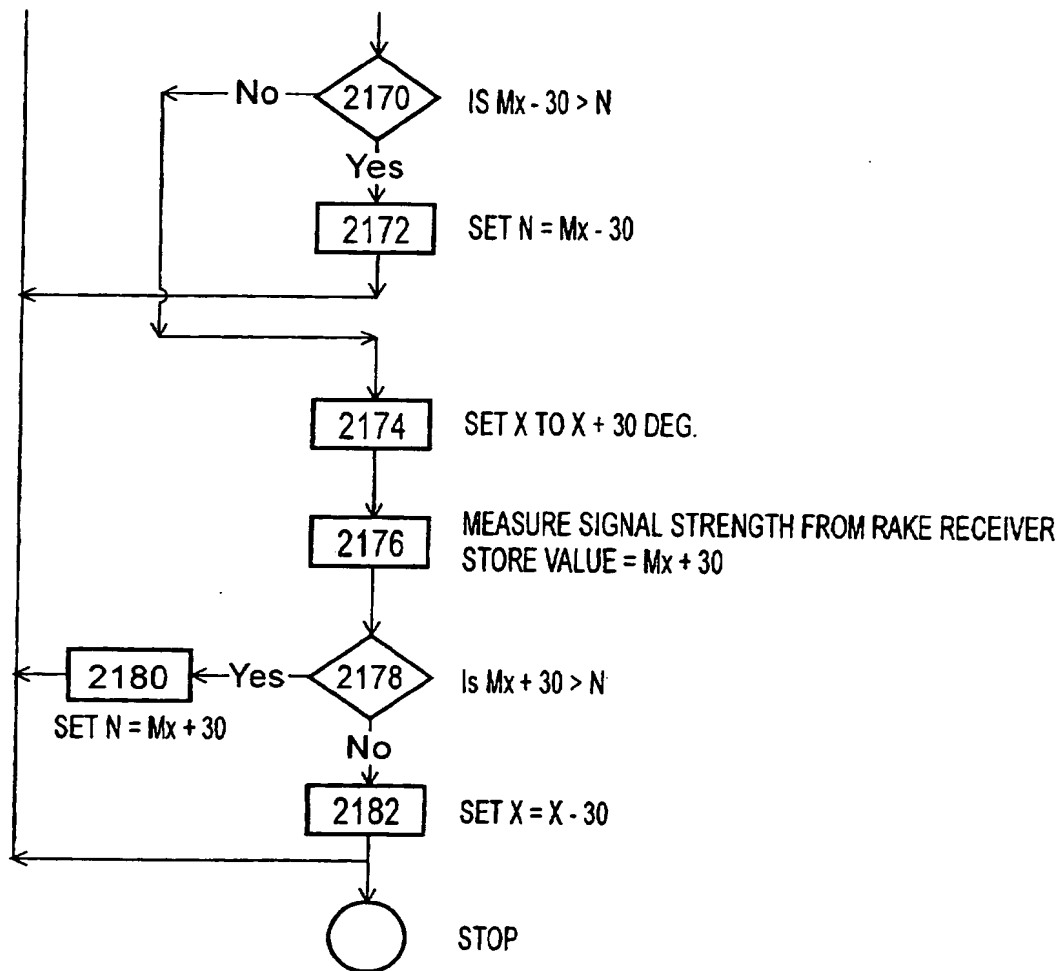


Fig. 21(d)

FLOW DIAGRAM FOR SET UP AND CONTROL OF STEERABLE ANTENNA FOR CDMA SYSTEM
WITH SENSOR FOR DETECTING CHANGES IN DIRECTION (Dt)

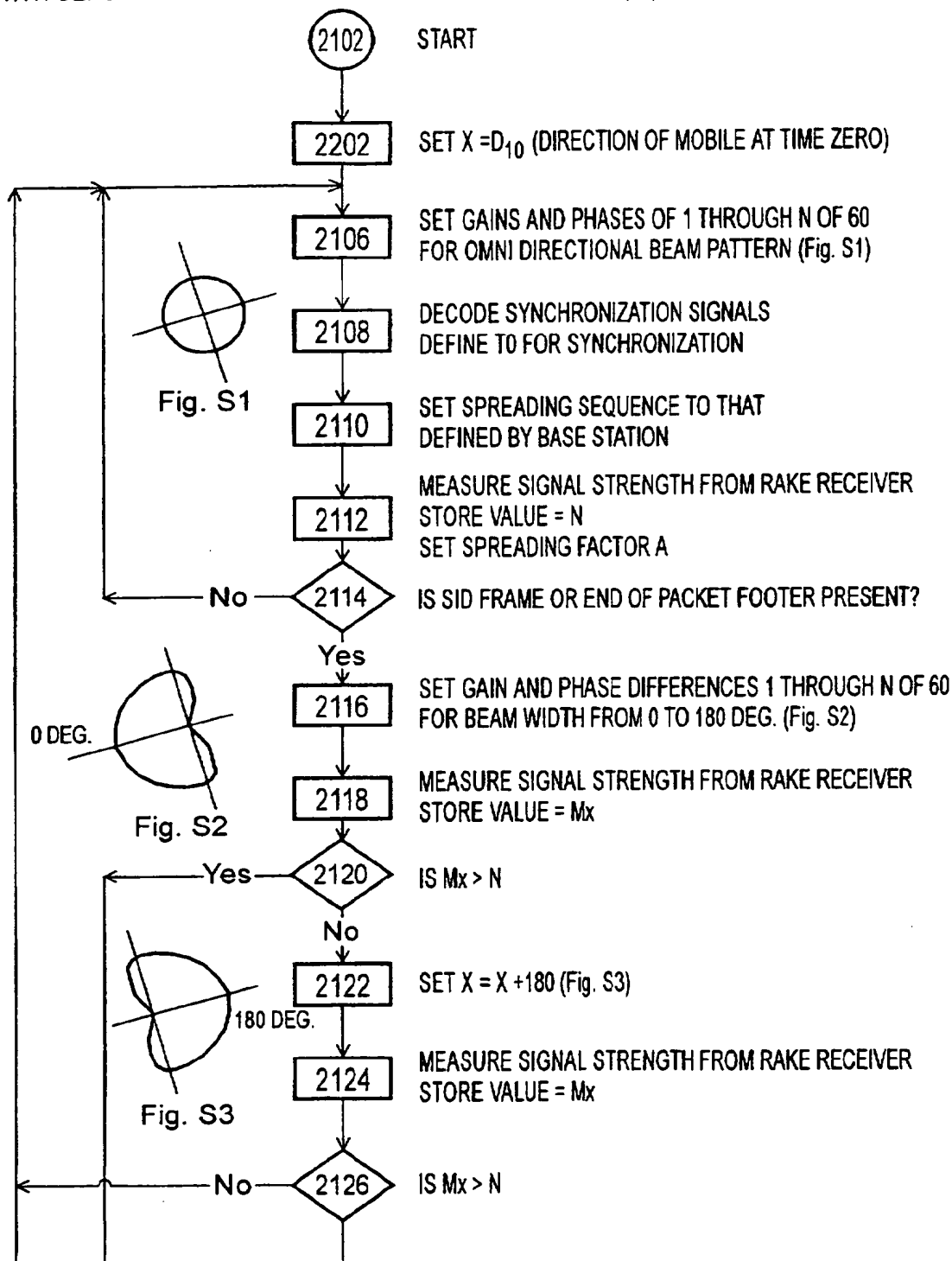


Fig. 22(a)

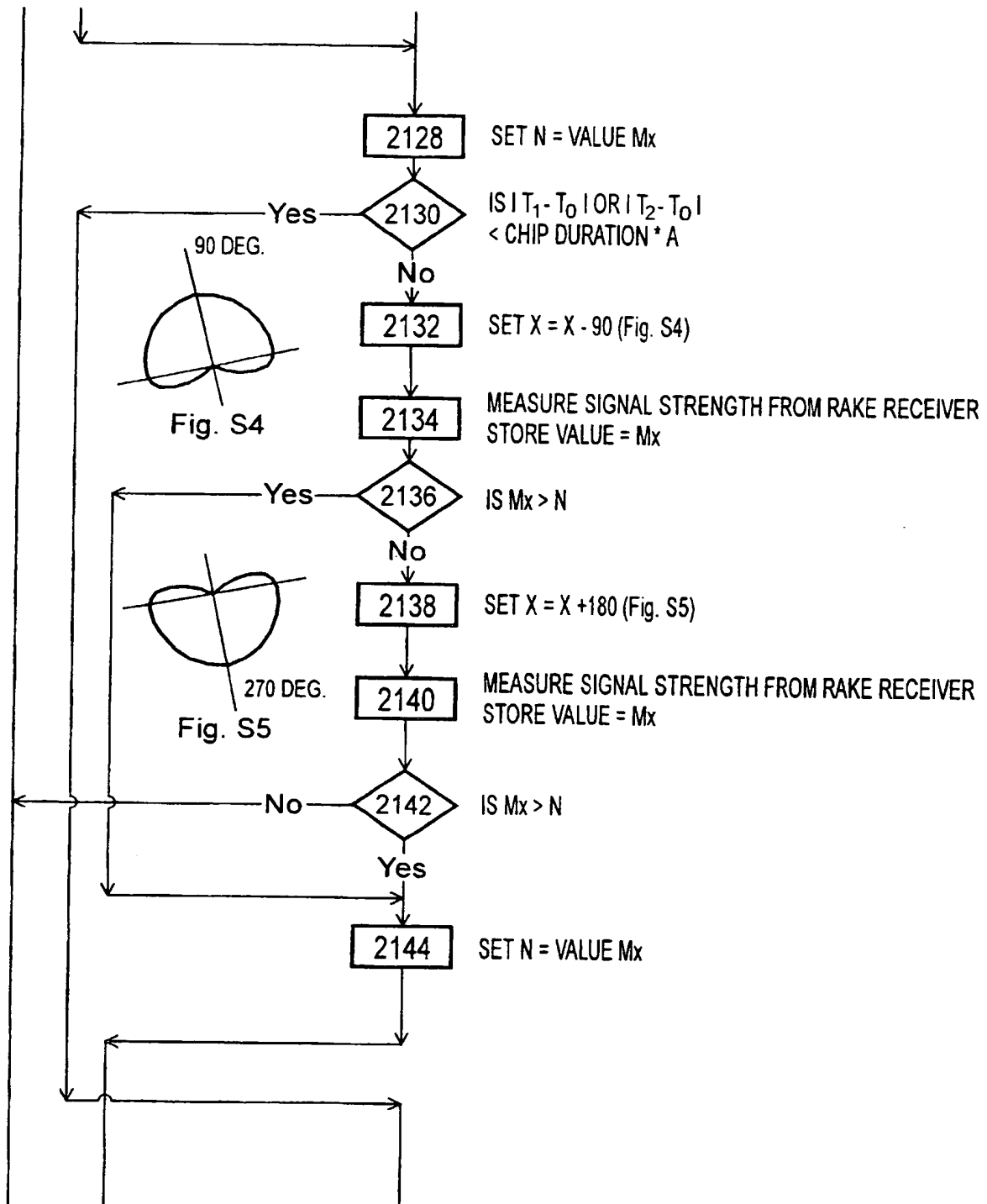


Fig. 22(b)

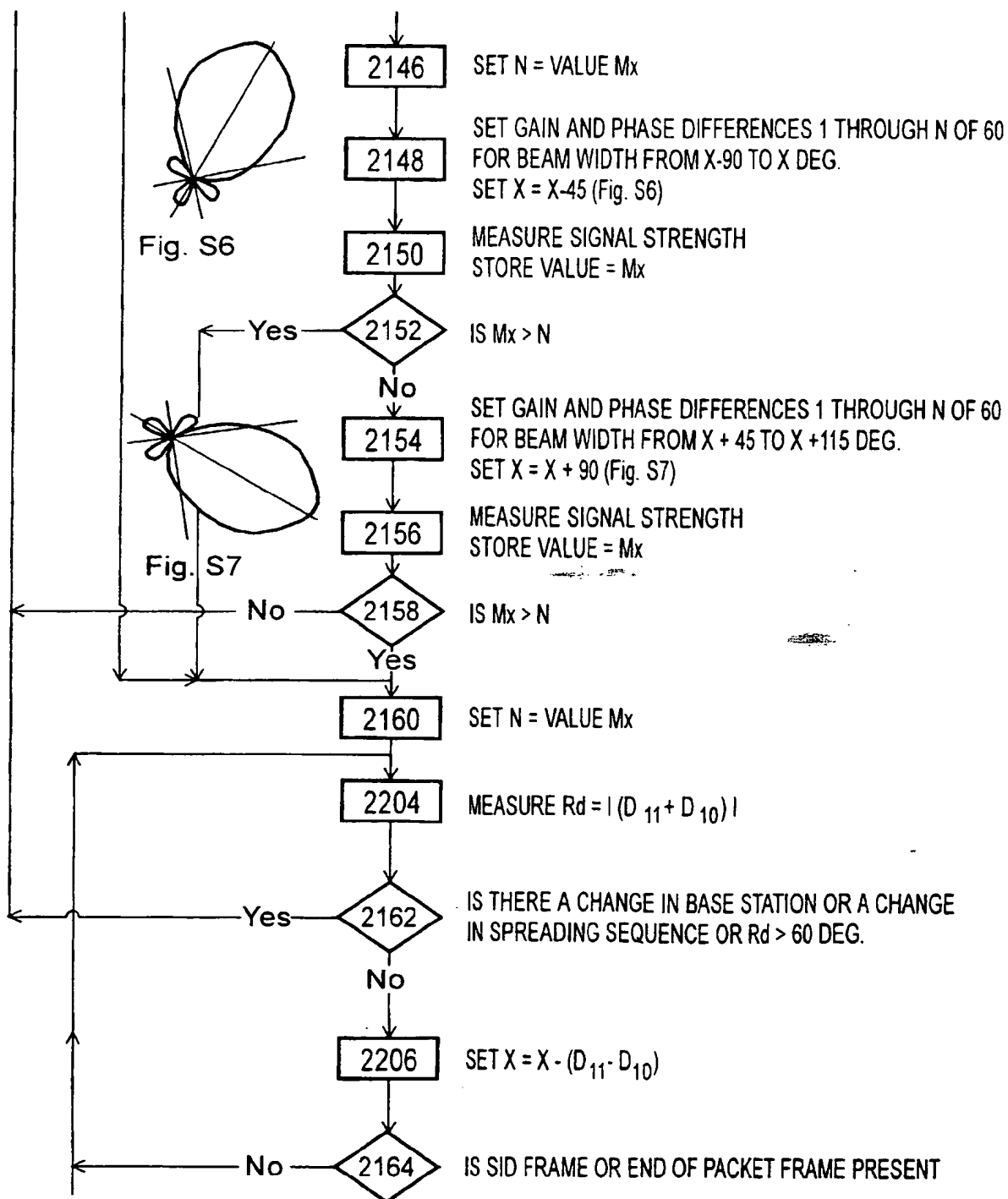


Fig. 22(c)

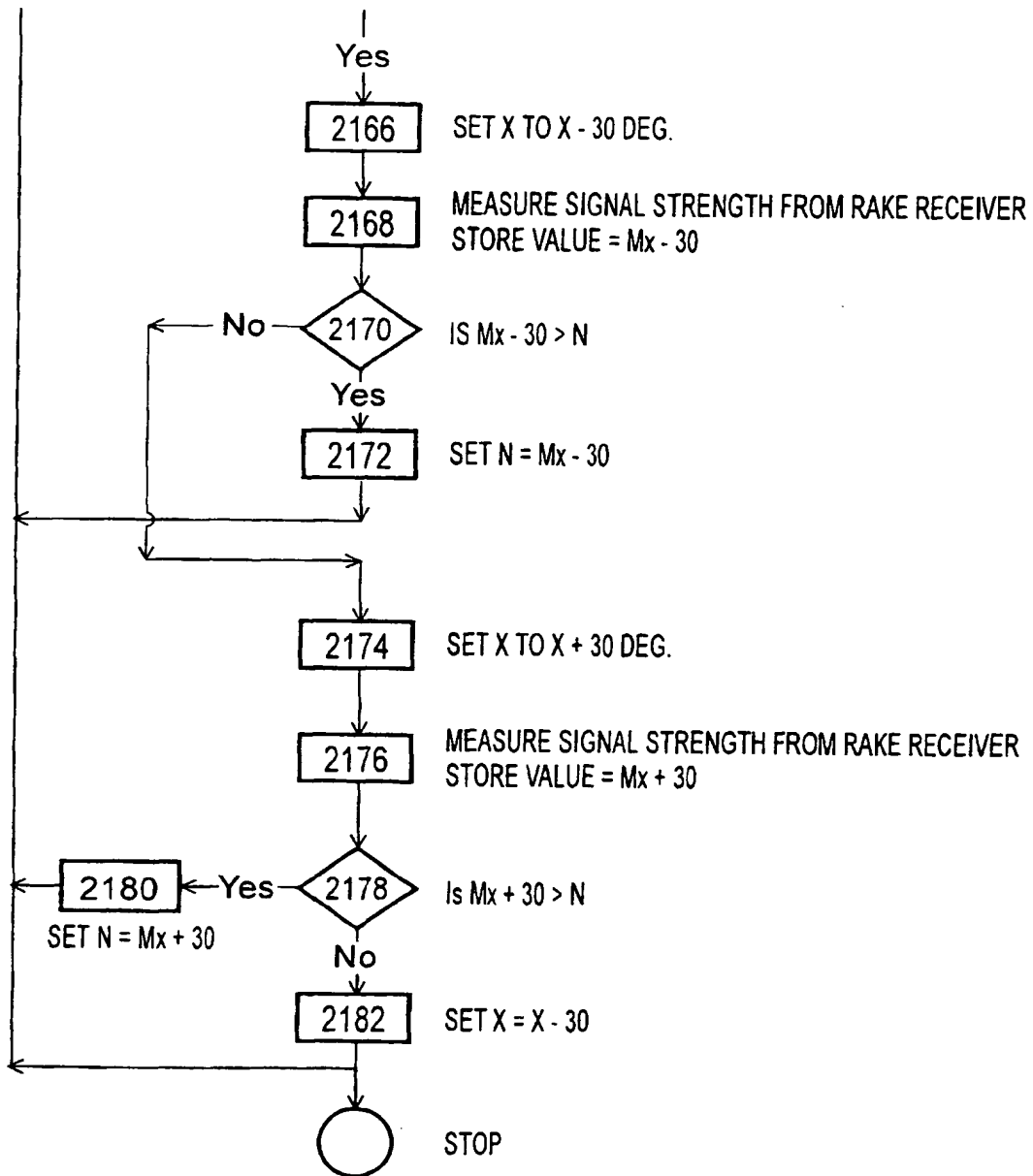


Fig. 22(d)



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 99 40 1573

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| The present search report has been drawn up for all claims | | | |
| Place of search THE HAGUE | | Date of completion of the search 26 November 1999 | Examiner López Márquez, T |
| CATEGORY OF CITED DOCUMENTS | | T : theory or principle underlying the invention E : earlier patent document, but published on, or after, the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document | |
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26-11-1999

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